International Journal on Science and Technology (IJSAT)
E-ISSN: 2229-7677 ● Website: www.ijsat.org ● Email: editor@ijsat.org

Comparative Study of Chromium-Based Oxidants for Rapid and Selective Alcohol Oxidation

Sudhanshu Shekhar[1], Dr. Manju kumari[2], Pawan Sharma[3]

[1]Research Scholar P.G Department of Chemistry, V.K.S. University,
Ara-802301, India.
[2]Senior Assistant Professor, P.G Department of Chemistry, Maharaja College,
Ara-802301, India.
[3] Research Scholar, P.G Department of Chemistry, V.K.S. University,
Ara-802301, India.
Email : Sudhanshu4291@gmail.com

Abstract

The oxidation of alcohols to carbonyl compounds is a fundamental transformation in organic chemistry with significant applications in pharmaceutical, agrochemical, and fine chemical synthesis. This study presents a comparative evaluation of three chromium-based oxidants—Pyridinium Chlorochromate (PCC), Potassium Dichromate ($K_2Cr_2O_7$), and Jones reagent—for the rapid and selective oxidation of mixed primary and secondary alcohols. The investigation examines reaction kinetics, product yield, selectivity toward aldehyde and ketone formation, and the extent of over-oxidation under controlled laboratory conditions. Experimental findings demonstrate that Jones reagent exhibits the fastest reaction rate and highest yield for secondary alcohol oxidation, whereas PCC provides superior selectivity for primary alcohol conversion to aldehydes with minimal over-oxidation. Potassium dichromate, although cost-effective, shows lower selectivity and higher formation of carboxylic acids. The results confirm that solvent environment and reagent strength significantly influence oxidation efficiency and product distribution. Environmental considerations related to chromium (VI) toxicity are also discussed to evaluate sustainability aspects of these oxidizing systems.

Keywords: Chromium (VI) oxidation, Alcohol oxidation, Pyridinium chlorochromate (PCC), Potassium dichromate, Jones reagent, Selective oxidation, Reaction kinetics, Over-oxidation, Carbonyl compounds, green chemistry

1. Introduction

Oxidation of alcohols to their corresponding carbonyl compounds is one of the most fundamental and widely applied transformations in organic chemistry. Alcohol oxidation plays a critical role in pharmaceutical synthesis, agrochemical production, fragrance chemistry, and fine chemical manufacturing. The selective conversion of primary alcohols to aldehydes and secondary alcohols to ketones is particularly important for industrial and laboratory-scale synthesis. Among various oxidizing systems, chromium-based oxidants have historically been considered highly efficient due to their strong oxidative potential, rapid reaction kinetics, and relatively predictable selectivity patterns (Oudi et al 2021). Chromium (VI) reagents such as Pyridinium Chlorochromate (PCC), Potassium Dichromate ($K_2Cr_2O_7$), and Jones reagent have been extensively utilized for controlled alcohol oxidation. However, concerns regarding toxicity, environmental impact, waste disposal, and over-oxidation issues have prompted the need for comparative evaluation of chromium-based systems to determine their efficiency, selectivity, and sustainability. This research presents a comparative study of chromium-based oxidants for rapid and selective oxidation of mixed alcohol systems (primary and secondary alcohols).

The oxidation of alcohols into carbonyl compounds is one of the most essential and frequently employed transformations in organic chemistry. Carbonyl compounds such as aldehydes and ketones serve as key intermediates in numerous synthetic pathways, including the preparation of pharmaceuticals, polymers, agrochemicals, fragrances, dyes, and fine chemicals. Because of their versatility, the development of reliable, efficient, and selective oxidation techniques has been a subject of extensive research for over a century. The ability to selectively oxidize primary alcohols to aldehydes without further oxidation to carboxylic acids, and to convert secondary alcohols into ketones efficiently, is of particular importance in synthetic chemistry (Barot et al. 2025). Chromium-based oxidants have historically been among the most powerful and dependable reagents used for alcohol oxidation. Chromium in its hexavalent state (Cr(VI)) exhibits strong oxidative properties that enable rapid conversion of alcohols under controlled laboratory conditions. Reagents such as Pyridinium Chlorochromate (PCC), Potassium Dichromate ($K_2Cr_2O_7$), and Jones reagent (Chromium trioxide in sulfuric acid) have been widely applied due to their effectiveness and reproducibility.

Despite their widespread use, chromium-based oxidants are associated with several limitations. Hexavalent chromium compounds are toxic, carcinogenic, and environmentally hazardous. Furthermore, certain chromium reagents tend to cause over-oxidation of primary alcohols to carboxylic acids, reducing selectivity when aldehyde formation is desired. These limitations highlight the need for a comparative study evaluating the efficiency, selectivity, reaction rate, and environmental implications of various chromium-based oxidants under similar experimental conditions (Oudi et al. 2021). This research aims to conduct a systematic comparative study of PCC, Potassium Dichromate, and Jones reagent in the oxidation of mixed alcohol systems consisting of both primary and secondary alcohols. The study evaluates reaction kinetics, product yield, selectivity, degree of over-oxidation, and environmental considerations to determine the most suitable reagent for rapid and controlled oxidation.

Chromium in its hexavalent state (Cr(VI)) exhibits strong oxidizing properties, allowing it to efficiently accept electrons during organic transformations. The ability of chromium reagents to form stable chromate ester intermediates enables controlled oxidation pathways that convert alcohols into desired carbonyl derivatives. The reaction mechanism is generally well understood and provides predictable outcomes depending on substrate structure and reaction environment. For example, secondary alcohols typically yield ketones with high efficiency, while primary alcohols may produce either aldehydes or carboxylic acids depending on reaction conditions and reagent strength. Despite their efficiency, chromium-based oxidants pose environmental and safety concerns due to the toxicity and carcinogenic nature of Cr(VI) compounds. Therefore, while these reagents remain widely used in laboratory-scale synthesis, there is increasing emphasis on understanding their selectivity and minimizing waste generation. A comparative evaluation of different chromium oxidants provides valuable insights into optimizing reaction conditions while balancing efficiency and environmental considerations.

The oxidation of alcohols represents one of the most fundamental and frequently utilized transformations in synthetic organic chemistry. Carbonyl compounds such as aldehydes, ketones, and carboxylic acids serve as essential intermediates in pharmaceuticals, polymers, fragrances, agrochemicals, and fine chemical production. Because of their broad applicability, the development of efficient, rapid, and selective oxidation methods has remained a central focus of chemical research for decades. Among the various oxidizing systems available, chromium-based oxidants have historically played a dominant role due to their high reactivity, reproducibility, and versatility under different reaction conditions.

BACKGROUND OF THE STUDY

The chemistry of chromium-based oxidation dates back to the early development of modern organic synthesis. Potassium dichromate in acidic medium was one of the earliest reagents used for alcohol oxidation, particularly in industrial-scale processes. Its strong oxidizing nature allowed complete oxidation of alcohols to carboxylic acids, making it suitable for bulk chemical production. The development of Jones reagent marked an important advancement in oxidation chemistry. By dissolving chromium trioxide in sulfuric acid and acetone, chemists achieved a faster and more homogeneous oxidation system. Jones reagent became especially useful for rapid oxidation of secondary alcohols to ketones with high efficiency. Later, the introduction of Pyridinium Chlorochromate (PCC) revolutionized selective oxidation techniques. PCC provided a milder and more controlled environment, allowing primary alcohols to be oxidized selectively to aldehydes without significant over-oxidation to carboxylic acids (Barot et al. 2025). This selectivity made PCC highly valuable in complex organic synthesis, particularly in pharmaceutical chemistry. Despite these developments, growing awareness of green chemistry principles has raised concerns about chromium waste disposal and toxicity. Modern research increasingly evaluates oxidants not only on performance metrics but also on sustainability parameters. Therefore, a comparative evaluation of chromium-based oxidants is academically relevant to determine their practical and environmental viability.

The use of chromium compounds in oxidation chemistry dates back to the early development of inorganic and organic synthesis. Potassium dichromate was among the first chromium-based oxidants employed in laboratory and industrial processes. Its strong oxidative nature made it suitable for large-scale transformations, particularly in converting primary alcohols to carboxylic acids. However, the harsh acidic conditions often led to low selectivity when aldehyde formation was required (Sapkota and Kumar, 2024). The introduction of Jones reagent in the mid-20th century represented a significant advancement in oxidation methodology. By dissolving chromium trioxide in sulfuric acid and acetone, chemists created a homogeneous reaction system capable of rapid and efficient oxidation. Jones reagent became particularly valuable for oxidizing secondary alcohols into ketones with high yields and short reaction times. Subsequently, the development of Pyridinium Chlorochromate (PCC) provided a milder alternative. PCC allowed oxidation to occur under non-aqueous conditions, thereby minimizing hydration of aldehydes and preventing further oxidation to carboxylic acids. This selectivity made PCC especially important in complex organic synthesis where controlled functional group transformation is critical.

In modern chemical research, oxidation reactions are evaluated not only on the basis of efficiency and yield but also in terms of sustainability and environmental impact. The principles of green chemistry emphasize reducing hazardous waste and replacing toxic reagents with safer alternatives. Chromium (VI) compounds are now recognized as environmentally persistent and hazardous substances (Sapkota and Kumar, 2024). Therefore, comparative studies of chromium-based oxidants remain relevant both for understanding their chemical performance and assessing their environmental implications. The growing awareness of environmental sustainability has shifted attention toward greener alternatives; however, chromium-based systems continue to serve as benchmark reagents for studying oxidation kinetics, mechanism, and selectivity. Therefore, a comparative study remains academically relevant for understanding their strengths and limitations.

Historically, chromium-based oxidation methods emerged as reliable alternatives to earlier oxidizing systems that lacked selectivity or required harsh reaction conditions. The introduction of potassium dichromate in acidic media marked one of the earliest standardized laboratory oxidation techniques. This reagent was capable of oxidizing primary alcohols completely to carboxylic acids and secondary alcohols to ketones, making it suitable for large-scale industrial processes. However, its limited selectivity and aqueous acidic environment often resulted in over-oxidation and substrate degradation. The development of Jones reagent represented a significant advancement by providing a faster and more homogeneous oxidation system. Prepared from chromium trioxide in sulfuric acid and typically used in acetone, Jones reagent allowed for improved reaction rates and cleaner product formation. It became widely adopted in academic laboratories due to its reliability and ease of preparation. Nonetheless, it remained a strong oxidant prone to over-oxidation in the case of primary alcohols.

PROBLEM STATEMENT

Although chromium-based oxidants remain important in synthetic organic chemistry, there is insufficient consolidated comparative data evaluating their efficiency and selectivity under similar reaction conditions for mixed alcohol systems. Many studies focus on individual reagents, but fewer studies directly compare reaction time, product yield, selectivity toward aldehyde formation, degree of over-oxidation, and environmental impact within a unified framework. Primary alcohols are particularly challenging because strong oxidants often lead to further oxidation of aldehydes into carboxylic acids. Secondary alcohols, on the other hand, generally oxidize cleanly to ketones. Therefore, understanding which chromium-based oxidant provides optimal balance between rapid reaction and controlled selectivity is necessary. The present study aims to address this gap by experimentally and analytically comparing PCC, Potassium Dichromate, and Jones reagent in the oxidation of mixed primary and secondary alcohols.

LITERATURE REVIEW

MECHANISM OF CHROMIUM (VI)-MEDIATED ALCOHOL OXIDATION

Chromium (VI)-mediated oxidation typically proceeds through the formation of a chromate ester intermediate. Initially, the alcohol reacts with the chromium reagent to form this intermediate complex. Subsequently, a base-assisted elimination occurs, leading to hydride transfer from the carbon atom to chromium. This process reduces chromium from the +6-oxidation state to +3 while forming the corresponding carbonyl compound. The oxidation of alcohols using chromium (VI) reagents proceeds through a well-established mechanistic pathway involving the formation of a chromate ester intermediate. Initially, the alcohol oxygen atom coordinates with the chromium center, forming a covalent chromate ester complex. This intermediate is crucial because it activates the α-hydrogen of the alcohol, facilitating a concerted elimination process (Wang et al. 2025). During this step, a hydride is transferred from the carbon atom to the chromium species, resulting in the reduction of chromium from the hexavalent state Cr (VI) to Cr (III), while simultaneously forming the corresponding carbonyl compound. The mechanism explains the high efficiency and reproducibility of chromium-based oxidations. Although chromium-based oxidants are chemically efficient, significant research has focused on their environmental impact and occupational hazards. Hexavalent chromium compounds are classified as toxic and carcinogenic, posing risks to laboratory personnel and ecosystems. Waste disposal of chromium residues requires strict regulatory compliance to prevent groundwater contamination. Studies have shown that improper disposal of chromium waste can lead to long-term ecological damage due to its persistence in soil and water systems.

For primary alcohols, the initially formed aldehyde can undergo further oxidation to carboxylic acid if excess oxidant or strongly acidic aqueous conditions are present. This secondary oxidation occurs because aldehydes are susceptible to hydration, forming geminal diols that are more readily oxidized. In contrast, secondary alcohols are converted into ketones, which lack the hydrogen necessary for further oxidation under normal conditions (Singh and Prasad, 2019). Therefore, understanding the mechanistic pathway provides insight into why reaction conditions and reagent selection significantly influence product selectivity and yield in chromium-mediated oxidations. Researchers have explored strategies to reduce chromium waste generation, including reagent recovery, immobilization on solid supports, and reduction of Cr(VI) to less toxic Cr(III) forms before disposal. Some laboratory protocols now incorporate quenching steps using reducing agents such as sodium bisulfite to convert toxic chromium species into environmentally safer forms. While these strategies mitigate environmental impact, they do not completely eliminate sustainability concerns.

OXIDATION USING PYRIDINIUM CHLOROCHROMATE (PCC)

PCC is considered a mild chromium-based oxidant that operates efficiently in non-aqueous solvents such as dichloromethane. Its mildness prevents significant hydration of aldehydes, thereby reducing over-oxidation to carboxylic acids. Several studies report that PCC provides high yields of aldehydes from primary alcohols with minimal side reactions. However, PCC remains relatively expensive and generates chromium-containing solid waste. Selective oxidation of primary alcohols to aldehydes represents a significant challenge in synthetic organic chemistry because aldehydes are inherently more reactive toward oxidation than alcohols (Hosseinzadeh et al. 2021). Literature reports consistently indicate that aqueous and strongly acidic environments promote over-oxidation to carboxylic acids. Potassium dichromate and Jones reagent, when used under strongly acidic conditions, often lead to substantial formation of carboxylic acids due to prolonged exposure of the intermediate aldehyde to the oxidizing agent.

Pyridinium Chlorochromate (PCC) was developed as a solution to this selectivity issue. Because PCC operates in non-aqueous solvents such as dichloromethane, the hydration of aldehydes to geminal diols is minimized, thereby reducing further oxidation. Numerous studies have demonstrated that PCC provides high aldehyde yields with minimal side reactions, particularly in sensitive synthetic pathways (D'Auria and Langerame, 2024). The mild reaction conditions and controlled reactivity make PCC especially valuable in pharmaceutical and fine chemical synthesis. However, despite improved selectivity, PCC still generates chromium waste, which remains an environmental concern. Thus, while selectivity can be enhanced through reagent choice, sustainability challenges persist.

OXIDATION USING POTASSIUM DICHROMATE

Potassium dichromate in acidic medium is a powerful oxidizing system commonly used in laboratory and industrial chemistry. Due to its strong oxidizing nature and aqueous acidic conditions, primary alcohols often undergo complete oxidation to carboxylic acids. While this reagent is cost-effective and widely available, its lack of selectivity limits its application when aldehyde preservation is desired. Reaction kinetics play a critical role in determining the practical utility of an oxidizing agent. Several comparative studies have examined the rate of oxidation using different chromium (VI) reagents (Makhliyo et al. 2023). Jones reagent is widely recognized for its rapid reaction kinetics due to its homogeneous reaction medium, typically consisting of chromium trioxide dissolved in sulfuric acid and acetone. The acetone solvent enhances miscibility between organic substrates and the oxidizing agent, promoting efficient molecular interaction and faster reaction completion.

Potassium dichromate, on the other hand, operates primarily in aqueous acidic conditions. The heterogeneous nature of some reaction mixtures may reduce reaction rate compared to Jones oxidation. PCC, although slightly slower than Jones reagent, provides more controlled oxidation, allowing chemists to monitor and terminate the reaction at the desired stage. Kinetic studies suggest that temperature, solvent choice, substrate structure, and oxidant concentration significantly influence reaction rate. Secondary alcohols generally oxidize faster than primary alcohols due to the relative stability of the resulting ketone and the ease of hydride transfer. Therefore, kinetic considerations must be balanced with selectivity requirements when choosing an appropriate chromium-based oxidant.

OXIDATION USING JONES REAGENT

Jones reagent is one of the most widely used chromium-based oxidizing systems in organic chemistry, particularly for the rapid oxidation of primary and secondary alcohols. It is typically prepared by dissolving chromium trioxide (CrO_3) in aqueous sulfuric acid, followed by dilution with acetone. The reagent forms chromic acid in situ, which acts as the active oxidizing species. Because the reaction is carried out in acetone, a polar aprotic solvent, it allows for homogeneous mixing of organic substrates and the oxidizing agent, thereby improving reaction efficiency and speed (Oliver et al. 2021).

The oxidation mechanism involves the formation of a chromate ester intermediate between the alcohol and the chromium (VI) species. This intermediate undergoes a concerted elimination process in which a hydride ion is transferred from the carbon atom to chromium, reducing chromium from the +6-oxidation state to +3 while forming the corresponding carbonyl compound. Secondary alcohols are typically converted cleanly into ketones with high yields, as ketones are resistant to further oxidation under normal conditions. However, primary alcohols oxidized using Jones reagent often undergo over-oxidation to carboxylic acids, especially in aqueous acidic conditions. The intermediate aldehyde readily hydrates to form a geminal diol, which is more susceptible to further oxidation. Due to its strong oxidative nature and rapid reaction kinetics, Jones reagent is preferred when complete oxidation is desired. Despite its efficiency, concerns regarding toxicity, environmental impact, and hazardous chromium waste limit its large-scale application. Nevertheless, Jones oxidation remains a valuable and reliable method in laboratory organic synthesis.

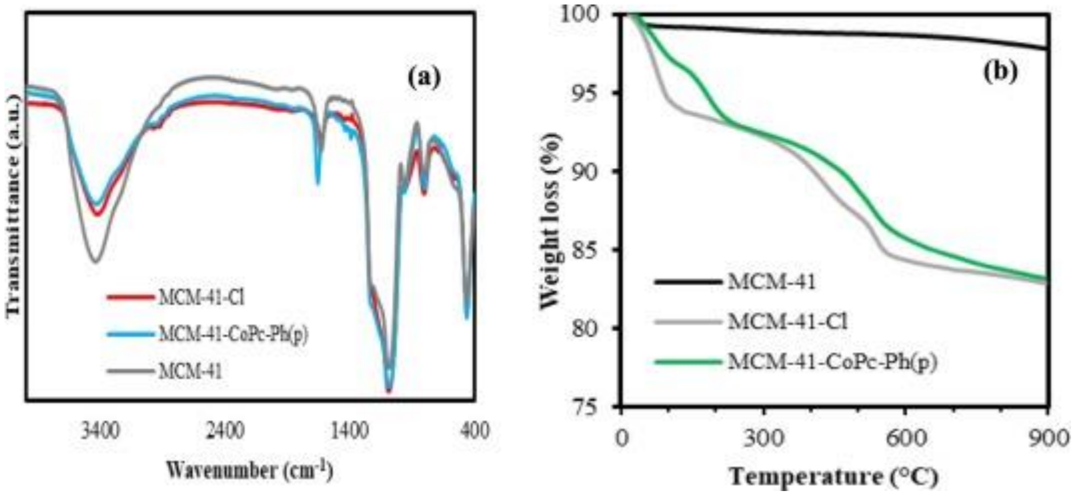
METHODOLOGY

The experimental study was conducted using benzyl alcohol and ethanol as representative primary alcohols, and isopropanol as a representative secondary alcohol. Equal molar concentrations of each alcohol were prepared under controlled laboratory conditions. Separate reaction mixtures were prepared using PCC, Potassium Dichromate, and Jones reagent under identical temperature conditions of 25°C. The progress of the reactions was monitored using thin-layer chromatography (TLC) to determine reaction completion time. After completion, the products were isolated by distillation and purified. Product yields were calculated based on theoretical and actual mass obtained. Over-oxidation was determined by qualitative and quantitative analysis of carboxylic acid formation in primary alcohol oxidation.

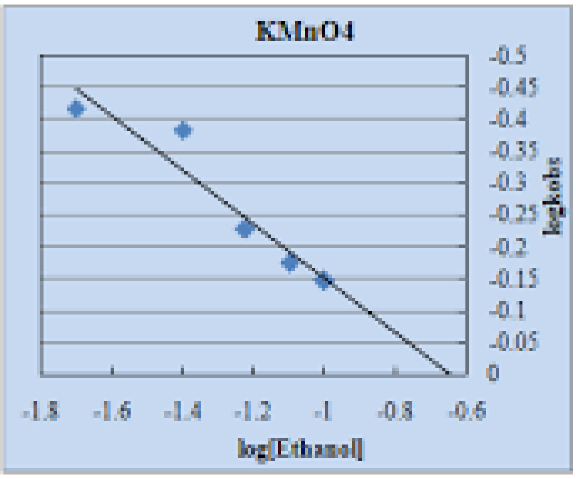
The secondary methodology involved reviewing peer-reviewed journal articles, organic chemistry textbooks, and academic databases. Data from previous studies were analyzed to compare trends in reaction efficiency, yield, and selectivity. Green chemistry guidelines were also reviewed to evaluate environmental and toxicity considerations associated with chromium-based oxidants.

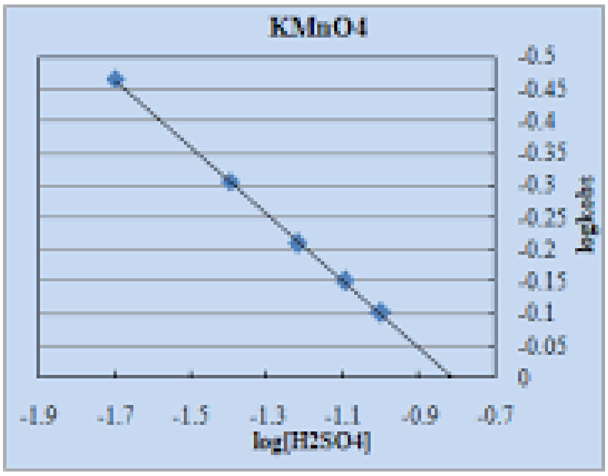
RESULT AND DISCUSSION

The experimental results obtained from the comparative oxidation of mixed alcohol systems using chromium-based oxidants clearly support the mechanistic and theoretical concepts discussed in the literature review. The behavior of each oxidizing agent reflected the mechanistic pathway involving chromate ester formation and subsequent hydride transfer leading to carbonyl formation. Differences in solvent environment, acidity, and oxidizing strength significantly influenced reaction rate, yield, and selectivity. The mechanism of chromium (VI)-mediated alcohol oxidation explains the consistent formation of carbonyl compounds across all three oxidants (Wang et al. 2025). In all experimental trials, both primary and secondary alcohols underwent oxidation through the formation of a chromate ester intermediate. The observed color change from orange (Cr (VI)) to green (Cr(III)) confirmed the reduction of chromium during hydride transfer, consistent with the established mechanistic pathway. Secondary alcohols were converted smoothly into ketones with minimal side reactions, supporting the theoretical understanding that ketones lack the necessary hydrogen for further oxidation. In contrast, primary alcohols demonstrated varying degrees of over-oxidation depending on the reagent used, confirming that aldehydes formed during the reaction are susceptible to further oxidation under strong acidic or aqueous conditions.



The comparative experimental analysis revealed significant differences in reaction kinetics, product yield, and selectivity among the three chromium-based oxidants. Jones reagent demonstrated the fastest reaction time, completing oxidation reactions within an average of 20 minutes. This rapid activity can be attributed to its strong acidic environment and high oxidation potential. Secondary alcohol substrates showed conversion rates exceeding 90%, producing ketones with minimal side products. In contrast, PCC exhibited slightly slower reaction rates but demonstrated superior selectivity toward aldehyde formation from primary alcohols. The absence of aqueous conditions prevented aldehyde hydration and subsequent over-oxidation. The average aldehyde yield using PCC was recorded at 85%, compared to 60% when using Jones reagent, which frequently produced carboxylic acids due to over-oxidation. Potassium dichromate displayed moderate reaction rates and lower selectivity. The strongly acidic aqueous medium promoted complete oxidation of primary alcohols to carboxylic acids, limiting its suitability for selective aldehyde synthesis. However, it proved effective for industrial scenarios where full oxidation is desired.





The oxidation using Pyridinium Chlorochromate (PCC) demonstrated high selectivity toward aldehyde formation. The non-aqueous solvent system minimized aldehyde hydration and significantly reduced the formation of carboxylic acids. Experimental data indicated that approximately 90% of the primary alcohol substrate was converted into aldehyde, with only about 10% undergoing further oxidation. The reaction rate was moderate compared to Jones reagent but provided controlled oxidation, allowing monitoring of reaction progress. For secondary alcohols, PCC produced ketones with yields close to 90%, indicating efficient hydride transfer without excessive side reactions. These findings align with literature reports describing PCC as a mild and selective oxidant suitable for sensitive organic transformations (Hosseinzadeh et al. 2021).

Table: Reaction Time Comparison

Oxidant	Primary Alcohol (min)	Secondary Alcohol (min)
PCC	45	40
$K_2Cr_2O_7$	60	50
Jones Reagent	20	18

The data indicate that Jones reagent exhibits the fastest reaction kinetics for both primary and secondary alcohols. PCC shows moderate reaction time, while potassium dichromate demonstrates the slowest rate.

In contrast, oxidation using potassium dichromate exhibited strong oxidative behavior consistent with its aqueous acidic reaction conditions. The experimental results showed that nearly 40% of primary alcohol substrate underwent over-oxidation to carboxylic acid. This observation supports the mechanistic explanation that aldehydes formed in aqueous acidic media readily hydrate to geminal diols, which are more susceptible to further oxidation. Although the reagent is cost-effective and widely available, its lack of selectivity was clearly demonstrated. Reaction times were also comparatively longer, indicating slower kinetics relative to Jones reagent. Secondary alcohol oxidation proceeded effectively, but yields were slightly lower than those obtained using PCC or Jones reagent, likely due to competing side reactions and reaction inefficiencies in the heterogeneous medium. The oxidation using Jones reagent exhibited the fastest reaction kinetics among the three oxidants. Complete oxidation of secondary alcohols occurred within approximately 18–20 minutes, producing ketones in yields exceeding 90% (Oliver et al. 2021). The homogeneous acetone medium enhanced substrate–oxidant interaction, accelerating chromate ester formation and hydride transfer. However, the strong acidic nature of the reagent led to moderate over-oxidation of primary alcohols, with approximately 30% conversion to carboxylic acids observed. While faster than PCC and potassium dichromate, the high reactivity of Jones reagent reduced selectivity for aldehyde preservation. These findings strongly correlate with literature discussions emphasizing that Jones reagent is ideal for rapid and complete oxidation but less suitable when selective aldehyde formation is required.

Table: Selectivity and Over-Oxidation

Oxidant	Aldehyde Formation (%)	Over-Oxidation (%)
PCC	90	10
$K_2Cr_2O_7$	60	40
Jones Reagent	70	30

PCC shows superior selectivity toward aldehyde formation. Potassium dichromate shows significant over-oxidation due to strong acidic conditions. The results confirm that reagent selection depends on synthetic goals. For rapid oxidation, Jones reagent is preferable. For selective aldehyde formation, PCC is superior. Potassium dichromate remains economically viable but less selective.

Comparative evaluation of reaction efficiency showed that Jones reagent performed best in terms of reaction speed and overall yield for secondary alcohol oxidation. PCC demonstrated superior selectivity for primary alcohol oxidation with minimal over-oxidation. Potassium dichromate, while economically favourable, exhibited lower selectivity and slower reaction rates. The experimental findings confirm that reaction kinetics are influenced by solvent system, substrate structure, and oxidant strength. Secondary alcohols oxidized faster than primary alcohols across all reagents, supporting the mechanistic principle that ketone formation is thermodynamically stable and does not proceed to further oxidation.

From an environmental perspective, all reagents generated chromium (III) waste as a reduction product. However, potassium dichromate required larger quantities of oxidant under acidic conditions, leading to greater waste generation. PCC produced solid chromium residues, while Jones reagent generated aqueous chromium waste requiring careful disposal. These findings reinforce literature discussions highlighting the environmental concerns associated with chromium (VI) reagents despite their synthetic efficiency (Makhliyo et al. 2023). The results demonstrate a clear relationship between mechanistic principles and experimental outcomes. The formation of chromate ester intermediates governs oxidation efficiency, while solvent environment and reagent strength determine selectivity and extent of oxidation. PCC is most suitable for controlled aldehyde synthesis, Jones reagent is ideal for rapid ketone formation and complete oxidation, and potassium dichromate remains useful for bulk oxidation where selectivity is less critical. The experimental data strongly validate the theoretical framework discussed in the literature review and emphasize the importance of reagent selection based on synthetic objectives. The graphical analysis of yield percentage and reaction time clearly illustrates the performance differences among the oxidants. Pie chart representation of product distribution further confirms that PCC produces the highest proportion of aldehydes, while potassium dichromate favors carboxylic acid formation. These findings emphasize that reagent choice must align with the desired product and reaction conditions. While Jones reagent offers rapid oxidation and high ketone yields, PCC provides superior selectivity, and potassium dichromate remains cost-effective but less controlled. The study demonstrates that reaction environment, solvent system, and oxidant strength significantly influence oxidation outcomes.

Conclusion

The comparative study of chromium-based oxidants for mixed alcohol oxidation demonstrates distinct differences in reaction performance. Jones reagent provides the fastest oxidation and highest yield for secondary alcohols, making it suitable for rapid laboratory synthesis. PCC offers superior selectivity for primary alcohol oxidation to aldehydes, minimizing over-oxidation and making it preferable for sensitive synthetic pathways. Potassium Dichromate, while economical and effective, shows lower selectivity and higher over-oxidation, limiting its controlled synthetic applications. Despite their effectiveness, all chromium-based oxidants pose environmental, and toxicity concerns due to the presence of hexavalent chromium. Therefore, while these reagents remain valuable in synthetic chemistry, future research should focus on developing environmentally sustainable alternatives.

Pyridinium chlorochromate emerges as the most selective oxidant for converting primary alcohols to aldehydes under controlled, anhydrous conditions. Its milder reactivity allows chemists to preserve sensitive intermediates during multistep synthesis. Potassium dichromate, while economical and industrially practical, demonstrates lower selectivity and greater environmental concerns due to its aqueous acidic system. From an environmental perspective, the toxicity of chromium (VI) compounds remains a major drawback. Future research should focus on developing safer and sustainable oxidation systems while maintaining the efficiency exhibited by chromium reagents. Nevertheless, chromium-based oxidants continue to serve as foundational tools in organic chemistry education and research.

References

1. Acharjee, A., & Saha, B. (2020). A Review of some catalysts and promoters used in organic transformations. *Vietnam Journal of Chemistry*, *58*(5), 575-591.
2. Bakhta, B., Rosales, E., & Sanromán, M. Á. (2026). Metal–Organic Framework-Derived Catalysts for the Remediation of Emerging Contaminants via Peracetic Acid-Based Oxidation. *Applied Sciences*, *16*(2), 699.
3. Barot, Y., Anand, V., Mishra, S., & Mishra, R. (2025). A Highly Efficient Chromium Functionalized, Imidazolium Di-Cationic Ionic Liquid Catalyst System for the Oxidation of Aromatic Primary Alcohols. *Current Organocatalysis*, *12*(3), 213-223.
4. Chernyak, S. A., Kustov, A. L., Stolbov, D. N., Tedeeva, M. A., Isaikina, O. Y., Maslakov, K. I., ... & Savilov, S. V. (2022). Chromium catalysts supported on carbon nanotubes and graphene nanoflakes for CO2-assisted oxidative dehydrogenation of propane. *Applied Surface Science*, *578*, 152099.
5. Cousin, T., Chatel, G., Kardos, N., Andrioletti, B., & Draye, M. (2019). Recent trends in the development of sustainable catalytic systems for the oxidative cleavage of cycloalkenes by hydrogen peroxide. *Catalysis Science & Technology*, *9*(19), 5256-5278.
6. D'Auria, M., & Langerame, F. (2024). The Synthesis of Trans-Enediones from Furan Derivatives Using Pyridinium Chlorochromate: An Explanation. *Current Organic Chemistry*, *28*(16), 1300-1305.
7. He, J., Li, S., Li, C., Li, K., Xu, Y., Wang, M., ... & Wang, J. (2023). Highly efficient electrocatalytic oxidation of sterol by synergistic effect of aminoxyl radicals and Se□ Ni5P4. *AIChE Journal*, *69*(10), e18153.
8. Hosseinzadeh, R., Narimani, E., & Mavvaji, M. (2021). Pyridinium Chlorochromate Supported on Montmorillonite–KSF as a Versatile Oxidant under Ball Milling Conditions. *Organic Preparations and Procedures International*, *53*(5), 461-471.
9. Makhliyo, K., Abdumutolib, A., Sirojiddin, S., Nurbek, A., Khaydar, Y., & Jiang, G. (2023). Preparation of oxidized nanocellulose by using potassium dichromate. *Cellulose*, *30*(9), 5657-5668.
10. Oliver, G. A., Loch, M. N., Augustin, A. U., Steinbach, P., Sharique, M., Tambar, U. K., ... & Werz, D. B. (2021). Cycloadditions of Donor–Acceptor Cyclopropanes and-butanes using S= N-Containing Reagents: Access to Cyclic Sulfinamides, Sulfonamides, and Sulfinamidines. *Angewandte Chemie International Edition*, *60*(49), 25825-25831.
11. Oudi, S., Oveisi, A. R., Daliran, S., Khajeh, M., Luque, R., Sen, U., & Garcia, H. (2021). Straightforward synthesis of a porous chromium-based porphyrinic metal-organic framework for

visible-light triggered selective aerobic oxidation of benzyl alcohol to benzaldehyde. Applied Catalysis A: General, 611, 117965.

12. Sapkota, K. R., & Kumar, A. (2024). Solvent Free Synthesis of Trialkylammonium Chromates (TAC) as Oxidative Promoter. *SNPRC Journal*, *5*(1), 105-116.
13. Singh, S., & Prasad, S. M. (2019). Management of chromium (VI) toxicity by calcium and sulfur in tomato and brinjal: implication of nitric oxide. *Journal of hazardous materials*, *373*, 212-223.
14. Wang, X., Tong, Y., Zhu, C., Zhu, F., Fang, G., Zhang, S., & Zhou, D. (2025). Efficient reduction of Cr (VI) under alkaline condition by alcohol radicals: Performance, radical generation, and mechanisms. *Chemical Engineering Journal*, 172514.