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# CONTINUOUS FLOW TERPENE SYNTHESIS: METAL PLATE REACTOR-ENABLED DIELS-ALDER REACTIONS

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**ABSTRACT**

This study presents an eco-friendly, high-efficiency protocol for the industrial production of terpenes using a continuous flow process with metal plate reactors. Traditional methods like batch processing for terpene production via the Diels-Alder reaction suffer from low efficiency, high waste disposal, and high costs due to stringent requirements. In the current study, the reaction parameters were optimized in a continuous flow setup, focusing on conversion, selectivity, and waste reduction to enhance economic viability. The results of optimization studies demonstrate that reaction completion is attainable at temperatures of 90°C and above, under conditions of 4 bar pressure, 1.05 mole equivalents of methyl pentenone, and 0.05 mol% % catalyst loading. The usage of polar solvents was found to adversely affect reagent conversion efficiency. The protocol was validated by comparison with batch methods and demonstrated reproducibility and scalability through a 24-hour continuous process, achieving a 95% mole yield and 96% conversion under optimized conditions. Analyses of Gas chromatography, GC-MS, $^{1}$H- and $^{13}$C-NMR were used to confirm the products. The findings support the industrial potential of the protocol for sustainable terpene production, reducing polymerization and minimizing by-products.

**Keywords:** Continuous Flow Process, Metal Plate Reactors, Terpenes, Diels-Alder Reactions, Flavour and Fragrances Molecules.

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## INTRODUCTION

The Diels-Alder reaction is a typical example of pericyclic [4+2] cycloaddition between conjugated dienes and dienophiles in organic synthesis.[1-2] The reaction has been extensively studied with various catalysts, including Lewis acids[3,5], organometallic catalysts[6], and other catalytic forms.[7-8] It plays a key role in medicinal chemistry[9–11], pharmaceutical industries[12], chemical industries, and fine chemicals.[13] This reaction is particularly significant in the flavour and fragrance industry, where it has a wide variety of applications, such as in the synthesis and manufacturing of fine chemicals. Also, it is reported that the Diels-Alder reaction can be used to produce compounds with enhanced sensory properties.[14-15] Key molecules in the flavour-fragrance sector, such as lyral, precyclemone derivatives, and myrac aldehydes, play major roles in composition.[16] These molecules require high levels of accuracy, reproducibility, and efficiency in chemical synthesis to meet stringent quality and safety standards. However, traditional batch processing has inherent limitations, including scalability issues[17], runaway reactions[18], challenges in handling reagents like aluminum chloride, alumina effluent generation, fluctuating reaction outcomes, and difficulties in controlling reaction conditions.[19] Consequently, the industry is considering continuous flow techniques as a better alternative to overcome these drawbacks.[20] Continuous flow chemistry has a lot of advantages over batch approaches[21-22], especially in the Diels-Alder reaction.[23] Flow reactors provide better mass and heat transfer, more control of reaction conditions, and ease of scale-up.[24] This method enhances safety by reducing the number of reactive components present at any one time while ensuring consistent product quality with improved yields.[25-26] Continuous flow systems can be coupled to inline analytical instruments for real-time monitoring and optimization towards enhancing process efficiency. The synthesis of flavour and fragrance compounds could undergo a revolution as demonstrated by recent developments in continuous flow technology.[27] To enhance the performance of the Diels-Alder reaction in flow, researchers have developed new types of reactors, adjusted reaction schemes, and tried various kinds of catalysts.[28] These achievements make it possible to produce high-value aroma compounds and intermediates efficiently, thereby demonstrating the merits associated with continuous flow technologies within this industry.[29-30] Renan Galaverna *et al.* investigated Diels-Alder reactions in a continuous flow process using


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a tubular reactor at 140°C and 10 bar pressure, achieving a throughput of 3.53 grams per hour. [31] However, these conditions are insufficient for industrial applications and are not optimized for operational safety. To address these issues, we modified the process by utilizing a minimal amount of boron trifluoride catalyst, allowing operation under mild conditions to enhance reaction efficiency. The aim of our research work is the synthesis and optimization of industrially relevant molecules over a continuous flow metal plate reactor via Diels-Alder reactions with a minimal amount of boron trifluoride as a catalyst. We improved the reaction conditions by changing different variables such as temperature, reagent mole ratios, boron trifluoride concentration, pressure, retention time, and solvent effects to increase product yield and reduce costs. GC and GC-MS were employed to separate the products, while $^{1}$H-NMR and $^{13}$C-NMR spectroscopy were used for characterization purposes. Accordingly, our work points out the effectiveness of the metal plate reactors in the continuous flow processing of industrially significant compounds synthesis using Diels-Alder reactions.

## EXPERIMENTAL

### Materials and Methods

Reagents, solvents, and chemicals of analytical quality were all utilized in this work. Myrcene, Myrcenol, 1,3-pentadiene, Isoprene, Methyl isoprene, Methyl pentenone, Acrolein, Methacrolein, Crotonaldehyde, and Mesityl oxide were purchased from Alfa Aesar. All the chemicals used were of 95% purity. Applying GC-MS, Varian-NMR, and Agilent-GC spectroscopic techniques, isolated compounds were described.

### Flow reactor Description

The FLOM pump and pressure sensors included in this use a Hastelloy metal plate reactor for investigation, allowing for digital back pressure monitoring [32], as shown in Fig.-1. The range of operation for the FLOM pump is 0.1 mL/min to 100 mL/min. According to Fig.-1, the Hastelloy metal plate flow reactor is connected by SS tubes and has a 10 mL capacity. The temperature range in which the reactor can function is -10°C to 150°C. A thermostat, capable of maintaining temperatures from -20°C to 200°C, is connected to ensure precise temperature control during the reaction. A digital back-pressure regulator, with a capacity of 0 bar to 20 bars, is connected to the reactor.

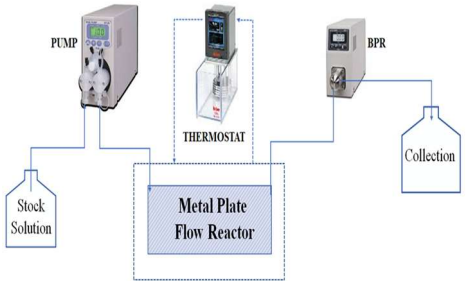



Fig.-1: Schematic Presentation of Continuous Flow Reactor

### Hastelloy Metal Plate Reactor

The metal plate reactor with a capacity of the reactor is 10 mL/min flow rate. The metal plate is designed by corvagation process as shown in Fig.-2, due to the design of the reactor substrate and reactants surface area will be high and provide good mixing.[33]

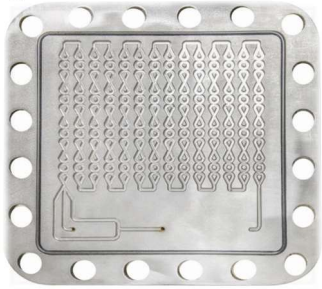


Fig.-2: Design of Metal Plate Reactor

The good mixing will help to complete the reactions instantly and improve productivity. The metal plate reactor module or segment has three main fluidic passages. As an illustration of a complete assembly of a fluidic segment, Fig.-3 is presented in Fig.-3, where process-side fluid flows through the middle passage while utility fluids flow through the upper and lower passages. This design allows for an increased area of heat transfer surface available to the process fluid.

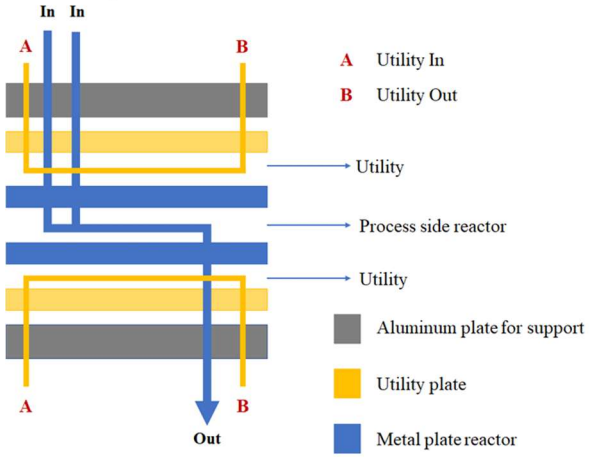



Fig.-3: Schematic Presentation of the Metal Plate Reactor

## RESULTS AND DISCUSSION

### Optimization Studies

The optimization studies were conducted using myrcene and methyl pentenone for the synthesis of Precyclemone via Diels-Alder reaction using boron trifluoride catalyst as illustrated in Fig.-4. The optimized conditions were obtained simply by changing the parameters such as temperatures, mole proportion of methyl pentenone, reaction pressures, mole percentage of boron trifluoride catalyst, and retention times.

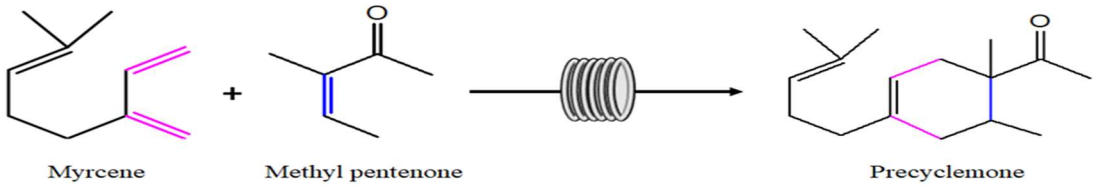



Fig.-4: Synthesis of Precyclemone from Myrcene and Methyl Pentenone via Flow Process in a Metal Plate Reactor

### Impact of Temperature

Optimization research was done to find out how temperature affected the Diels-Alder reaction. The stock solution was prepared with 0.2 moles of myrcene, 0.22 moles of methyl pentenone, and 0.15 mol% % of catalyst diluted in 100 ml of ethyl acetate solvent. The reaction was performed by varying between 60°C and 110°C in temperature, at 4 bar pressure and 2 mins reaction time, as depicted in Fig.-5 (a). Reactions were found to be incomplete at 60°C to 80°C, with a lower conversion rate due to lower temperatures. Complete conversion was achieved at 90°C and higher temperatures. Given that lower temperatures are preferable for operational efficiency, 90°C was chosen as the ideal reaction temperature for additional screening.

### Impact of the Mole Ratio of Methyl Pentenone

By altering the mole equivalents, the impact of the methyl pentenone reagent concentration was investigated from 1.0 to 1.3 moles at a temperature of 90°C, 4 bar pressure with 2 mins reaction time, the stock solutions were prepared by 0.2 mole of myrcene, varying mole ratios of methyl pentenone and 0.15 mole % of catalyst diluted to 100 ml of ethyl acetate solvent. As shown in Fig.-5 (b). At 1.0 mole equivalent of methyl pentenone, a 90% conversion was observed, while complete conversion of 96% was achieved at 1.05 and

1.1 mole equivalents. For mole equivalents between 1.15 and 1.3, the reaction was completed, but slightly lower conversions were obtained. These results indicate that an excess amount of reagent adversely affects the conversion rate due to by-product formation. Therefore, for further optimization studies, 1.05 mole equivalent of methyl pentenone was selected as the optimal amount.

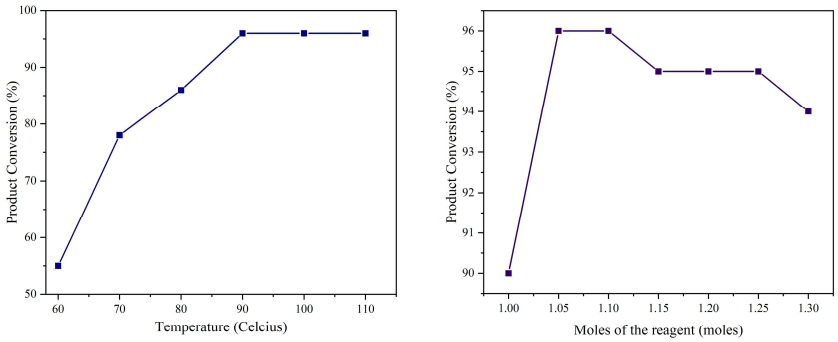



Fig.-5: Optimization Studies for the Synthesis of Precyclemone (a) Temperature Effect (b) moles of Methyl Pentenone

**Impact of Pressure**

The reaction was furtherly investigated under optimized conditions by varying pressures using a mixture of 0.2 moles of myrcene, 0.21 moles of methyl pentenone, and 0.15 mol% % of catalyst diluted in 100 ml of ethyl acetate solvent. The results indicated an 84% conversion at 0 bar pressure and a 91% conversion at 2 bar pressure, with lower conversions attributed to improper mixing. The reactions were completed at pressures of 4 bar to 10 bar, as illustrated in Fig.-6 (a). From a safety perspective, lower pressures are preferred. Therefore, 4 bar pressure was chosen as the ideal state for additional research.

**Impact of the Mole Ratio of Boron Trifluoride Catalyst**

The impact of catalyst quantity was investigated by altering the mole equivalents of boron trifluoride from 0.025 mole% to 0.15 mole% at a temperature of 90°C, 4 bar pressure, with 2 2-minute reaction time. The stock solutions were prepared by 0.2 mole of myrcene, 0.21 moles of methyl pentenone, and various mole% % of catalyst diluted to 100 ml of ethyl acetate solvent, as shown in Fig.-6 (b). In the presence of 0.025 mol% % of catalyst, a conversion of 90% was observed, while complete conversion of 96% was achieved at 0.05 mol% % to 0.15 mol% % of catalyst. Fewer catalysts will be economical and have potential for minimal wastage in the process. Therefore, for further optimization studies, 0.05 mole% % of the catalyst was selected as the optimal amount.

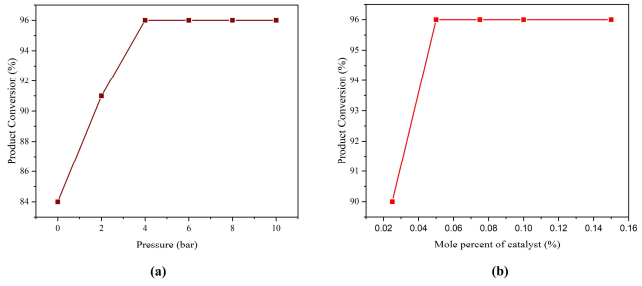



Fig.-6: Optimization Studies for the Synthesis of Precyclemone (a) Effect of Pressure (b) Mole Ratio of Boron Trifluoride

**Impact of Reaction Time**

Using 0.2 moles of myrcene, 0.21 moles of methyl pentenone, and 0.05 mol% boron trifluoride catalyst in 100 ml of ethyl acetate solvent at 90°C and 4 bar pressure, the reaction performance was examined by adjusting the flow rates or residence periods. Table-1 provides a summary of the findings. It was found that inadequate reagent mixing prevented the reactions from being finished at residence times of 0.5 and 1.0 minutes. It was shown that conversion rose to 95% at a reaction time of 1.5 minutes. Nevertheless, the replies were finished at residence periods of 2.0, 3.0, and 4.0 minutes. In terms of economics and

productivity, shorter retention periods are desirable. As a result, the ideal retention time was determined to be 2.0 minutes. Our optimization experiments' findings showed that 1.05 mole equivalents of methyl pentenone at 90°C, 4 bars of pressure, and a retention period of 2.0 minutes were the most effective flow process parameters.

Table-1: Effect of Reaction Time for the Synthesis of Precyclemone

| Flowrate (mL/min) | Reaction time (min) | Conversion (%) |
|---|---|---|
| 20 | 0.5 | 88 |
| 10 | 1 | 92 |
| 6.66 | 1.5 | 95 |
| 5 | 2 | 96 |
| 3.33 | 3 | 96 |
| 2.5 | 4 | 96 |

**Impact of Solvent**

The effects of several solvents were investigated under ideal circumstances in order to improve the reaction protocol's economic and environmental friendliness. Several solvents were added to the stock solutions to assess the reaction performance. The solvent screening was conducted using 1.05 mole equivalents of methyl pentenone and 0.05 mol % of catalyst at 90°C at 4 bar pressure with a 2.0-min retention time. It was observed that ethyl acetate, methanol, and acetone resulted in complete conversion of reagents, while dimethyl formamide showed a 95% conversion rate. The usage of hexane as the solvent resulted in lower conversion due to its low polarity. In the absence of solvent, an 85% conversion was observed, which was found to be moderate, and the reaction is incomplete. As given in Fig.-7, except for hexane, all other solvents performed better in terms of conversion percentage. However, the recovery and recycling of ethyl acetate were particularly efficient compared to other solvents used for the current study. Therefore, ethyl acetate was chosen as the optimized solvent for both economic and environmental benefits.

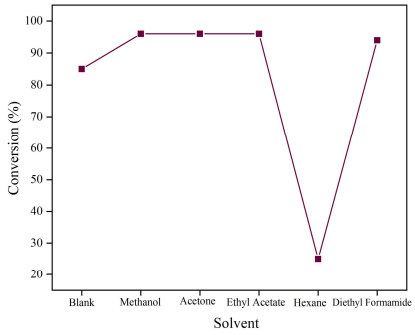



Fig.-7: Solvent Impact for the Synthesis of Precyclemone using a Continuous Flow Process

**Comparative Studies in Batch Process**

We conducted the reaction again using the optimized flow conditions to confirm their effectiveness of conventional batch processes for the synthesis of Precyclemone from myrcene and methyl pentenone.

Table-2: Synthesis of Precyclemone via Conventional Batch Process

| Boron trifluoride (mole% %) | Methyl pentenone (mole) | Conversion (%) |
|---|---|---|
| 0.05 | 1.05 | 25% |
| 0.1 | 1.1 | 54% |
| 0.2 | 1.2 | 94% |

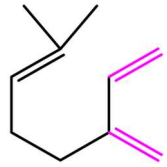
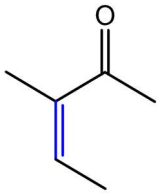
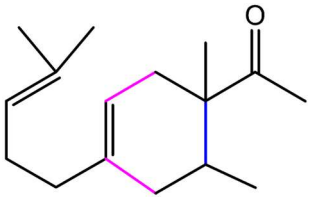
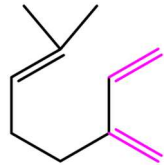
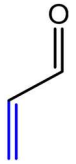
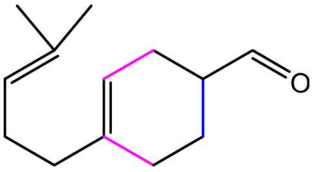
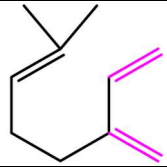
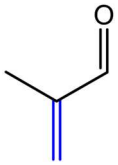
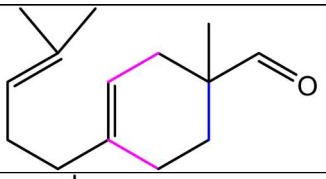
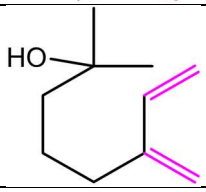
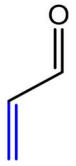
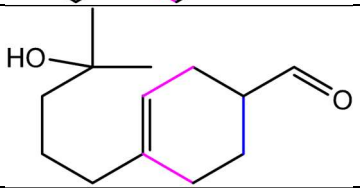
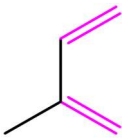
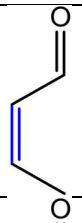
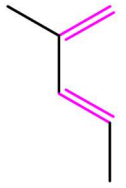
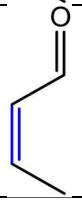
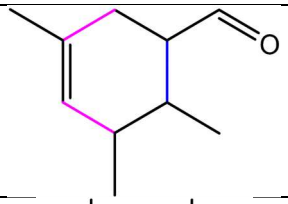
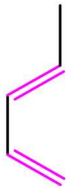
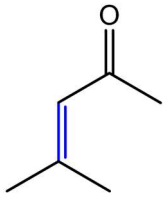
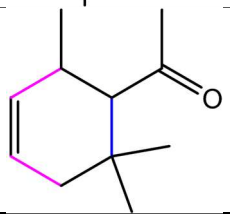
As detailed in Table-2, the reaction was carried out with a 1.05 mole ratio of methyl pentenone and 0.05 mol% boron trifluoride catalyst in ethyl acetate solvent under reflux temperature (75-80°C), resulting in lower conversion. To improve the yield, the experiment was conducted again with a 1.1 mole ratio of methyl pentenone and 0.1 mol% of boron trifluoride catalyst in ethyl acetate solvent, which obtained 54% of conversion. Complete conversion was obtained with a 1.2 mole ratio of methyl pentenone and 0.2 mol% boron trifluoride catalyst under reflux (75-80°C) temperature with a reaction time of 30 minutes. These

results indicate that the batch process requires more reagents and catalysts for the completion of the reaction due to lower temperatures, atmospheric pressures, and reduced mixing efficiency.

**Diels-Alder Reaction Scope via Continuous Flow Method**

As shown in Fig.-1, the scope of the reaction was examined using a variety of terpenes under ideal circumstances. Table-3 displays the isolated yields of the Diels-Alder reaction products, which were carried out utilizing a variety of substrates.

Table-3: Scope of the Diels-Alder Reaction for the Industrially Relevant Molecules via a Continuous Flow Process Using a Metal Plate Reactor

| Entry | Substrate | Reagent | Products | Yield |
|---|---|---|---|---|
| 1 |  |  |  | 95 % |
| 2 |  |  |  | 94 % |
| 3 |  |  |  | 97 % |
| 4 |  |  |  | 96 % |
| 5 |  |  |  | 94 % |
| 6 |  |  |  | 93 % |
| 7 |  |  |  | 92 % |

Reaction Parameters: flowrate - 5 mL/min, Temperature - 90°C, Reaction pressure - 4 bar, Reaction time - 2 min.

**Scalability of Continuous Flow Process in Diels-Alder Reaction**

To validate the scalability of the protocol, the reaction was conducted using a large concentration of Precyclemone (Entry-01) at an optimized scale. The substrate was continuously pumped for 60 mins, and 186.5 grams of pale yellowish-coloured liquid product was isolated after purification, achieving a mole yield of 95%. The resulting product was 4.476 kg per 24 hours using a 10 mL metal plate reactor. The isolated product confirmed the efficiency of the reaction on a larger scale, demonstrating its economic viability and suitability for economically efficient manufacturing practices as reported in Table-4.

Table-4: Comparison of Diels-Alder Reaction Productivity for Economic Impact on the Synthesis of Industrially Important Compounds

| Reactor type | Temperature (°C) | Pressure (bar) | Reaction Time (min) | Productivity per 24 hours | References |
|---|---|---|---|---|---|
| Tubular reactor | 140 | 10 | 40 | 0.084 kg | 31 |
| Tubular reactor and Plate reactor | 140 | - | 40 | 2.79 kg | 29 |
| Metal plate reactor | 90 | 4 | 2 | 4.476 kg | Current work |

**General Procedure for Synthesizing Cyclic Terpenes using Continuous Flow Process**

To prevent moisture contamination, the required substrate and reagent solutions for the Diels-Alder reaction were prepared and stored in a nitrogen atmosphere. A 2M substrate solution was made for the Stock Solution by dissolving 0.2 mol of substrates, 0.21 mol of reagents, and 0.05 mol% of boron trifluoride catalyst in 100 mL of ethyl acetate. First, ethyl acetate was used to prime the flow system for 15 to 20 minutes. As illustrated in figure 6.1, the stock solutions were poured into a 10 mL capacity Hastelloy metal plate flow reactor at a flow rate of 5.0 mL/min. The reactor had a residence time of two minutes at 90°C and 4 bars of back pressure. After the reaction, the product was collected and quenched using an ice-cold water solution. The organic phase was separated, washed with water, and then dried on sodium sulphate. The solvent was then vacuumed off to yield crude oils. These crude oils were characterized using GC, GC-MS, $^{1}$H- and $^{13}$C-NMR techniques.

**Precyclemone (Entry-1)**

Yield: 95 %; Pale yellowish colour clear liquid; Purity: 98% by GC; m/z value: 234; Solvent-$CdCl_3$;400 MHz, $^{1}$H-NMR: δ ppm 1.01 (3H, d, J = 6.8 Hz), 1.24 (3H, s), 1.59-1.63 (6H, 1.59 (s), 1.63 (s)), 1.75 - 2.05 (5H, (1H, dd, J = 7.4 Hz), 1.95 - 2.03 (4H, dd, J = 10.0 Hz)), 2.16 (s), 2.07 - 2.13 (2H, dd, J = 7.4 Hz), 2.29 (2H, dd, J = 15.4 Hz), 5.07 (1H, t, J = 5.3 Hz), 5.38 (1H, t, J = 7.2 Hz). $^{13}$C-NMR: δ ppm 17.611 (1C, s), 20.434-20.502 (2C, 20.434 (s), 20.502 (s)), 25.594 (1C, s), 28.872 (1C, s), 31.612 (2C, s), 37.357 (1C, s), 40.331 (2C, s), 44.682 (1C, s), 120.058 (1C, s), 123.989 (1C, s), 131.358 (1C, s), 135.039 (1C, s), 197.239 (1C, s).

**Myrac Aldehyde (Entry-2)**

Yield: 92 %; Pale yellowish colour clear liquid; Purity: 96% by GC; m/z value: 192; Solvent-$CdCl_3$;400 MHz, $^{1}$H-NMR: δ ppm 1.58-1.69 (6H, 1.58 (s), 1.69 (s)), 1.936-2.29 (8H, 1.95 (2H, t, J = 7.4 Hz), 2.00 (2H, dd, J = 13.9 Hz), 2.15 (2H, t, J = 7.4 Hz), 2.29 (dd, J = 14.2 Hz)), 2.39 (2H, dd, J = 14.6 Hz), 2.439-2.481 (1H, m), 5.058-5.423 (2H, 5.062 (dd, J = 7.0 Hz), 5.423 (t, J = 7.2 Hz)), 9.686 – 0.698 (1H, d, J = 4.7 Hz). $^{13}$C NMR: δ ppm 22.426-23.724 (2C, 22.426 (s), 23.426 (s)), 24.384 (1C, s), 25.561 (1C, s), 26.76 (1C, s), 27.33 (1C, s), 37.495 (1C, s), 45.951 (1C, s), 118.297 (1C, s), 123.998 (1C, s), 131.422 (1C, s), 137.875 (1C, s), 204.55 (1C, s).

**Precyclemone-B (Entry-3)**

Yield: 97 %; Pale yellowish colour clear liquid; Purity: 96.7% by GC; m/z value: 206; Solvent-$CdCl_3$;400 MHz, $^{1}$H-NMR: δ ppm 1.04 (3H, s), 1.42-1.67 (6H, 1.604 (s), 1.676 (s)), 1.834-1.1.872 (2H, dd, J = 15.2

Hz), 1.934 (2H, t, J = 7.4 Hz), 1.951-2.101 (6H, dd, J = 7.4, 7.2 Hz)), 2.237-2.362 (2H, dd, J = 12 Hz ), 5.06-5.389 (2H, 5.06 (dd, J = 6.4 Hz), 5.389 (t, J = 7.2 Hz)), 9.469 (1H, s). $^{13}$C-NMR: δ ppm 20.434-20.502 (2C, 20.434 (s), 20.502 (s)), 21.974 (1C, s), 25.594 (1C, s), 28.872 (1C, s), 34.465 (1C, s), 37.357 (1C, s), 37.645 (1C, s), 44.431 (1C, s), 120.058 (1C, s), 123.989.1 (1C, s), 131.358 (1C, s), 137.239 (1C, s), 205.758 (1C, s).

**Lyral (Entry-4)**
Yield: 96 %; Pale yellowish colour clear liquid; Purity: 98.5% by GC; m/z value: 210; Solvent-$CdCl_3$;400 MHz, $^1$H-NMR: δ ppm 1.22-1.32 (6H, 1.27 (s), 1.27 (s)), 1.397-1.491 (4H, 1.397 (quint, J = 7.5 Hz), 1.471 (t, J = 7.5 Hz)), 1.667-1.724 (2H, m), 1.938 - 2.026 (4H, dd, J = 13.9 Hz), 2.231-2.238 (2H, dd, J = 14.2 Hz), 2.468 (1H, m), 5.433 (1H, dd, J = 7.0 Hz), 9.692-9.707 (1H, d, J = 4.7 Hz). $^{13}$C-NMR: δ ppm 22.407 (1C, s), 26.603 (1C, s), 27.089 (2C, s), 29.176 - 29.221 (2C, 29.176 (s), 29.221 (s)), 37.88 (1C, s), 43.359 (1C, s), 45.985 (1C, s), 70.853 (1C, s), 118.518 (1C, s), 137.877 (1C, s), 204.749 (1C, s).

**Triplal (Entry-5)**
Yield: 94 %; Pale yellowish colour clear liquid; Purity: 95% by GC; m/z value: 138; Solvent-$CdCl_3$;400 MHz, $^1$H-NMR: δ ppm 0.956 - 0.998 (3H, d, J = 6.7 Hz), 1.63 (3H, s), 1.697 - 1.868 (2H, q, J = 13.1 Hz), 1.924 - 2.06 (2H, dd, J = 14.7 Hz), 2.478-2.716 (2H, 2.57 (m, J = 10.1 Hz), 2.61 (dd, J = 6.7 Hz)), 5.381-5.403 (1H, d, J = 4.7 Hz), 9.785 (1H, d, J = 4.9 Hz). $^{13}$C-NMR: δ ppm 17.006 (1C, s), 28.294 (1C, s), 28.673 (1C, s), 29.736 (1C, s), 50.165 (1C, s), 53.365 (1C, s), 125.896 (1C, s), 133.624 (1C, s), 205.37 (1C, s).

**Isocyclocitral (Entry-6)**
Yield: 93 %; Pale yellowish colour clear liquid; Purity: 98% by GC; m/z value: 152; Solvent-$CdCl_3$;400 MHz, $^1$H-NMR: δ ppm 1,269 (6H, d, J = 6.6 Hz)), 1.54 (3H, s), 1.94 (1H, dd, J = 10.1 Hz), 2.18-2.35 (3H, 2.25 (dd, J = 6.6 Hz), 2.27 (dd, J = 14.3 Hz)), 2.64 (1H, dd, J = 10.1 Hz), 5.24 (1H, d, J = 5.2 Hz), 9.73 (1H, d, J = 4.4 Hz). $^{13}$C-NMR: δ ppm 19.738-19.898 (2C, 19.738 (s), 19.898 (s)), 25.159 (1C, s), 37.077-37.927 (2C, 37.077 (s), 37.927 (s)), 56.101 (1C, s), 61.339 (1C, s), 125.372 (1C, s), 132.569 (1C, s), 206.987 (1C, s).

**1-(2,6,6-Trimethyl-cyclohex-3-enyl)-ethanone (Entry-7)**
Yield: 92 %; Pale yellowish colour clear liquid; Purity: 96% by GC; m/z value: 166; Solvent-$CdCl_3$;400 MHz, $^1$H-NMR: δ ppm 0.96-1.17 (9H, 1.01 (s), 1.12 (d, J = 6.8 Hz)), 1.95 (2H, dd, J = 15.1, 2.8 Hz), 2.07 (3H, s), 2.39 (1H, d, J = 4.0 Hz), 3.08 (1H, dd, J = 6.8, 4.0, 2.1 Hz), 5.28 (1H, dt, J = 10.2, 2.8 Hz), 5.51 (1H, dd, J = 10.2, 2.1 Hz). $^{13}$C-NMR: δ ppm 17.006 (1C, s), 28.294-28.673 (2C, 28.294 (s), 28.673 (s)), 29.691 (1C, s), 33.691 (1C, s), 36.736 (1C, s), 40.165 (1C, s), 57.376 (1C, s), 123.858 (1C, s), 133.624 (1C, s), 208.37 (1C, s).

## CONCLUSION

The current study synthesized industrially relevant terpenes from dienes and dienophiles via the Diels-Alder reaction using continuous flow processes with a metal plate reactor. The reaction was optimized using myrcene and methyl pentenone to synthesize Precyclemone, with boron trifluoride as the catalyst. The study results showed that cyclic terpenes were synthesized under mild conditions: 90°C temperature, 4 bar pressure, 1.05 mole equivalents of methyl pentenone, and 0.05 mol % catalyst, yielding a 96% conversion rate. A 10 mL metal plate reactor, operating under a continuous flow process for 24 hours, yielded 4.476 kg of product, confirming the reproducibility and the ability of the process to resolve polymerization issues and limit by-product formation. The reaction was carried out using standard batch procedures to confirm the effectiveness of the optimized flow conditions. High product yields of 92-97% were obtained by conducting the reaction with different terpenes under ideal flow conditions on a gram scale, confirming the reaction's scope.

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## CONFLICT OF INTERESTS

The authors declare that they have no conflict of interest.

## AUTHOR CONTRIBUTIONS

The present work is related to *SDG-9: Industry, Innovation and Infrastructure*. All the authors contributed significantly to this manuscript, participated in reviewing/editing and approved the final draft for publication. The research profile of the authors can be verified from their ORCID ids, given below:

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