Reaction optimization using an advanced photoflow reactor set-up towards a climate neutral industry

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Light-up
Reaction Optimization

Introduction

The Light-Up project aims to optimize photochemical reactions using light as a sustainable energy source. Flow reactors, which enhance light energy absorption, are commonly employed in photochemical reactions to contribute to the transition toward a climate-neutral society (fig. 1).

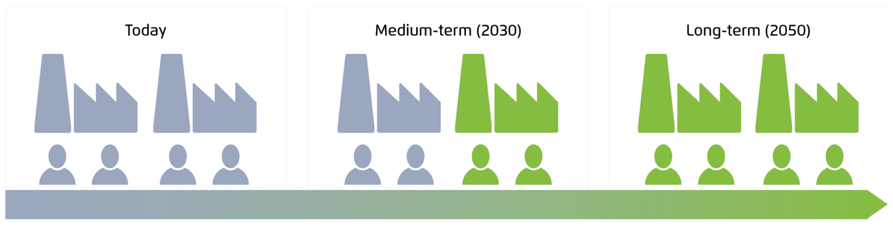

Fig. 1: The transformation of a basic industrial company on the road to climate-neutral production. [1]

This research aims to optimize the trifluoromethylation and thiol-ene click in flow, improving conversion, yield, and sustainability. It also focuses on building a flow reactor setup with a heterogeneous catalyst for the thiol-ene click reaction.

Materials & Method

The trifluoromethylation (fig. 2) and thiol-ene click rection (fig. 3) were performed using the Labtrix Start flow reactor (fig. 4) using either blue or white light.

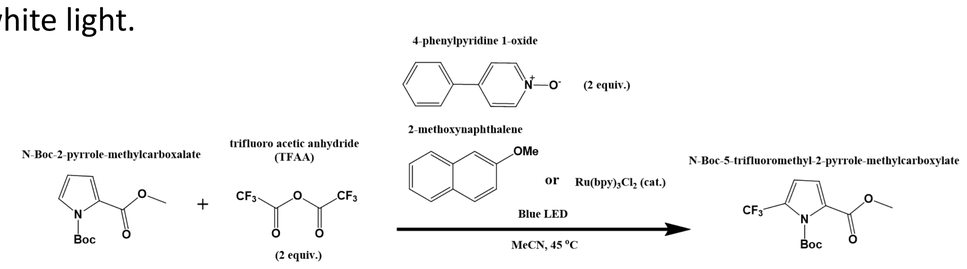

Fig. 2: The selected literature reaction for trifluoromethylation.[2]

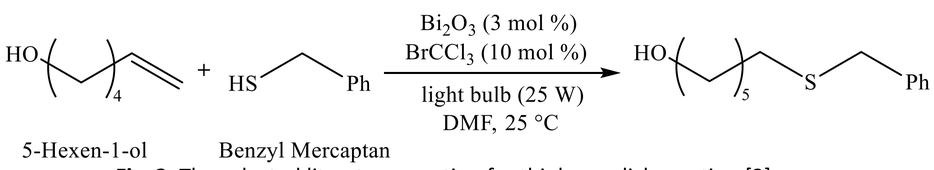

Fig. 3: The selected literature reaction for thiol-ene click reaction.[3]

Fig. 4: Labtrix Start flow reactor set up.

The reaction mixtures were analyzed with ^{19}F-NMR, ^{1}H-NMR, HPLC and GC to determine the purity, yield and conversion.

Results & Discussion

Trifluoromethylation:
The yield of the batch reaction was lower than the yield in literature [2] (fig. 5). This can be explained by the difference in used light source and by the shorter reaction time.

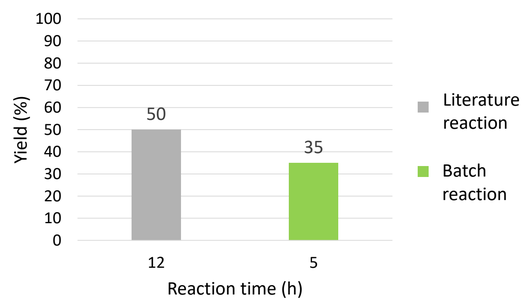

Fig. 5: Reproducibility literature results.

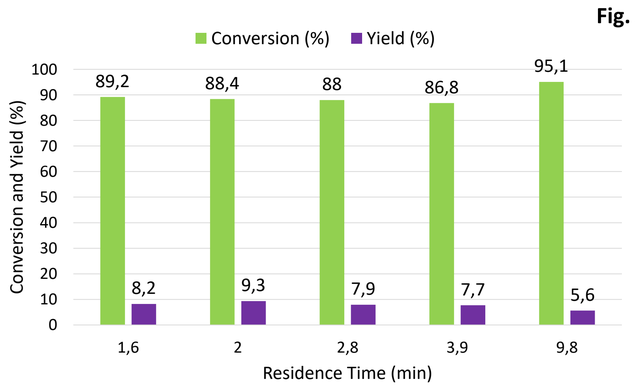

Fig. 6: Effect of different residence times on conversion and yield.

Longer residence times in the flow reactor led to a higher conversion (fig. 6). This was, however, accompanied by a lower yield. This is thought to be caused by the degradation of either the starting material or the product by the high intensity light.

Results & Discussion

The reactions testing the effect of light intensity (in flow) showed that the higher light intensities resulted in a higher conversion and a higher yield (fig. 7).
The 2-methoxynaphtalene was not activated by blue light, giving no yield and conversion.
Purifying of the product was not yet succeeded.

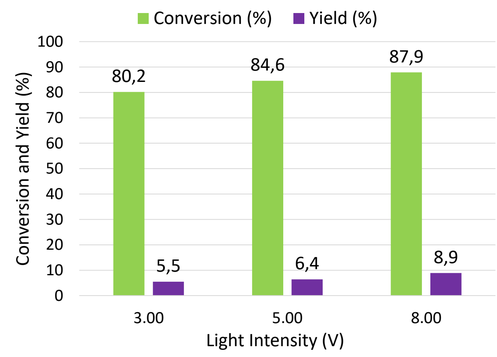

Fig. 7: Effect of different light intensities on conversion and yield.

Thiol-ene Click Reaction:
The obtained yield was lower in comparison to the reported literature [3], suggesting the possibility of catalyst degradation as a reason. However, when benzil was used as a more sustainable catalyst, a significantly higher yield was found (fig 8). Lastly, the reaction was performed in a continuous flow using the Labtrix Start reactor set up. Despite the relatively lower yield, the result is promising, achieved within a short reaction time of 0.03 h.

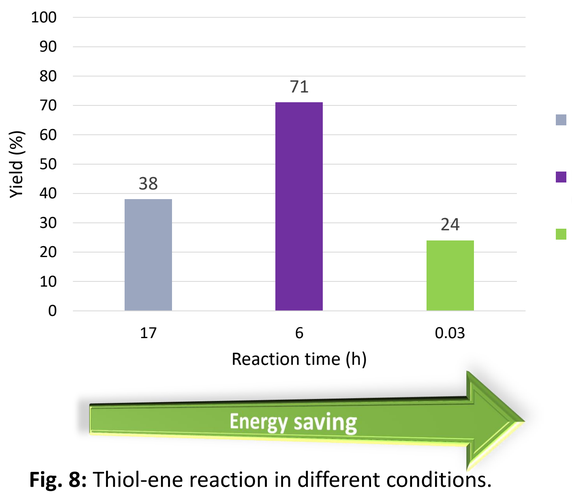

Fig. 8: Thiol-ene reaction in different conditions.

In order to scale up the thiol-ene reaction. A dedicated setup, utilizing the HANU reactor, was designed and constructed to allow the use of a heterogeneous catalyst on a larger scale (Fig. 9). Integrating filters in the design enables the retention of the heterogeneous catalyst inside of the reactor.

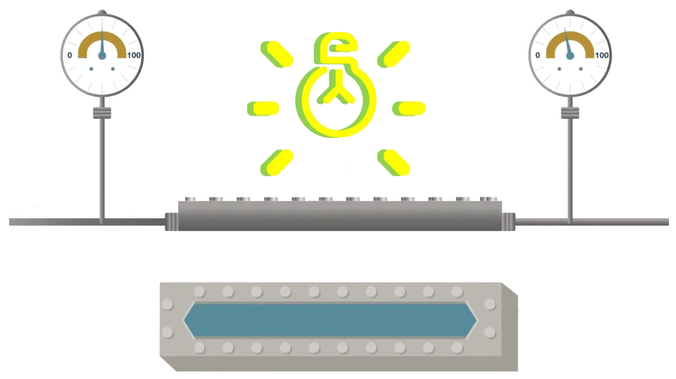

Fig. 9: HANU reactor built for the thiol-ene click reaction.

Conclusion & Recommendation

Trifluoromethylation:
- High conversion and the formation of a new compound were shown.
- Separation from the reaction mixture was challenging due to structural similarity.
- Higher conversion but lower yield was obtained with a longer residence time, likely due to light-induced degradation.
- Testing an alternative catalyst had limited success. CF3SO2Cl shows potential for enhanced yield and atom efficiency. [4]
- Addressing product separation challenges and optimizing reaction parameters are crucial for future research and advancing this reaction in synthetic chemistry.

Thiol-ene Click Reaction:
- Batch reaction had a lower yield compared to the literature.
- Catalyst degradation could be the cause of this discrepancy.
- Benzil as a green catalyst showed promise.
- The Labtrix reaction demonstrates the potential of flow systems for enhancing reaction efficiency.
- Future research should focus on greener solvent alternatives.

[1] Agora Energiewende. (2018). Climate-neutral industry: Strategies for a net-zero emissions future. Agora Energiewende: Retrieved from https://www.agora-energiewende.de/en/publications/climate-neutral-industry-executive-summary/
[2] J. J. D. R. M. R. C. M. K. P. C. C. R. S. Joel W. Beatty, “Photochemical Perfluoroalkylation with Pyridine N-Oxides: Mechanistic Insights and Performance on a Kilogram Scale,” Chem, vol. 1, no. 3, pp. 456-472, 2016.
[3] O. O. Fadeyi, J. J. Mousseau, Y. Feng, C. Allais, P. Nuhant, M. Z. Chen, B. Pierce and R. Robinson, “Visible-Light-Driven Photocatalytic Initiation of Radical Thiol−Ene Reactions Using Bismuth Oxide,” Organic letters, pp. 1-4, 30 September 2015.
[4] H. H. S. a. O. E. Kim, Recent developments in visible-light-catalyzed multicomponent trifluoromethylation of unsaturated carbon–carbon bonds, 2018.

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