

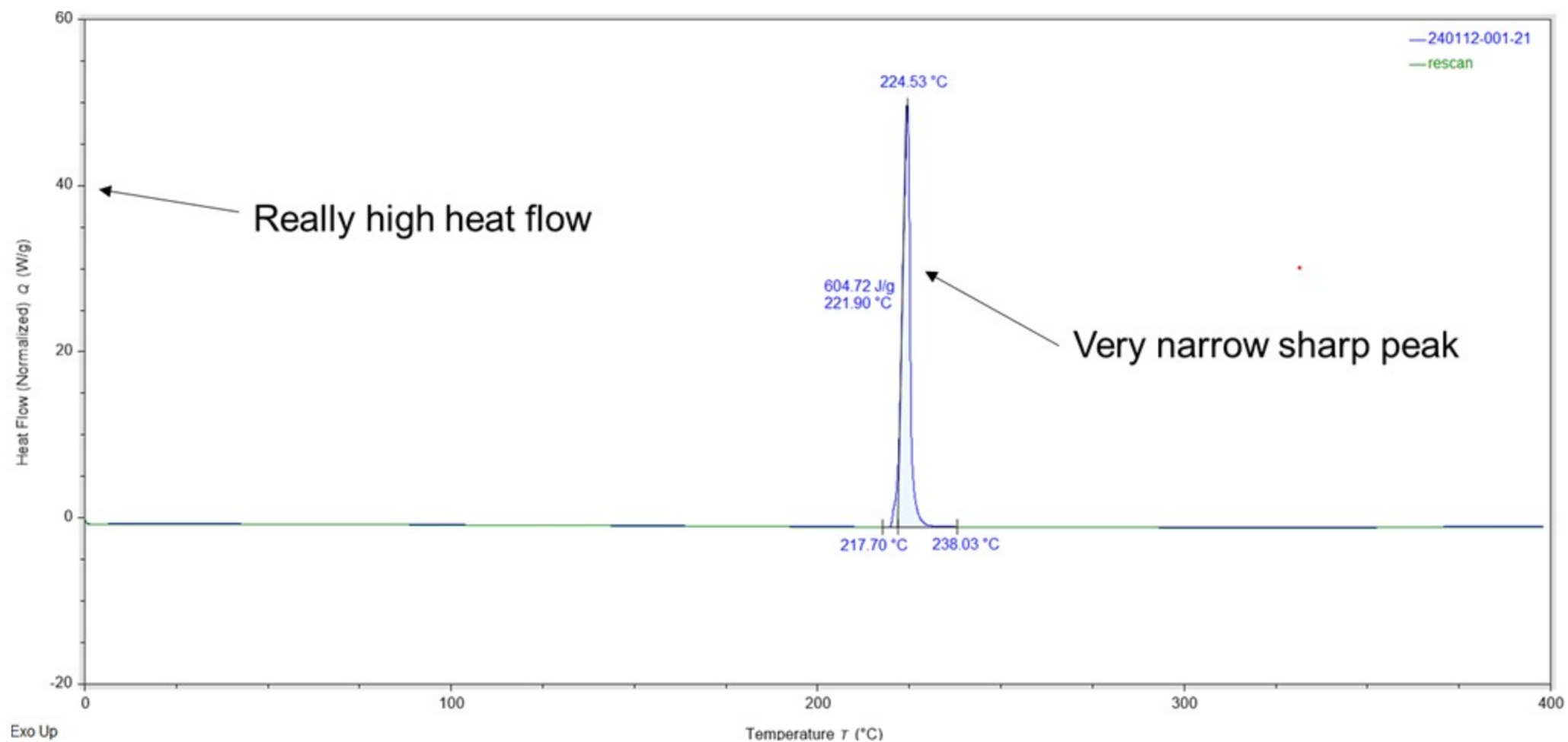


Difluoromethoxy Arenes and Why Materials of Construction Matter

Daniel Valco - Corteva Reactive Chemicals Technical Leader

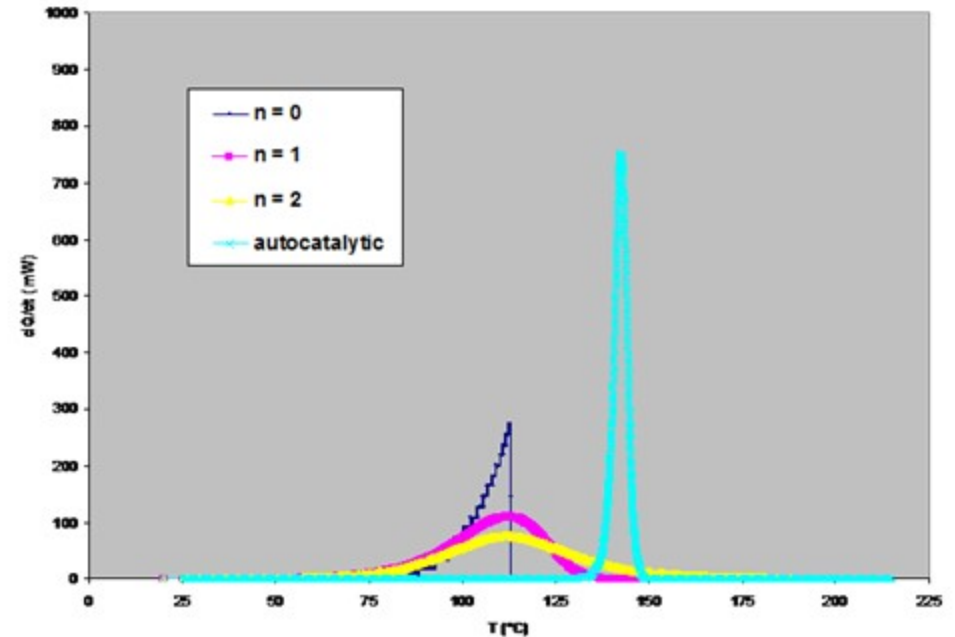
P2SAC FALL MEETING DEC 4 2024

The story begins with a DSC test...



Autocatalysis study (quick review of 2022 P2SAC pres.)

- An autocatalytic reaction indicates that at least one of the products is also a catalyst for the same reaction.
- The reaction rate increases with conversion and only a small amount of heat before self-accelerating.
- Chemicals that undergo autocatalytic decomposition can self-accelerate under isothermal conditions during storage and **the onset temperature is affected by the thermal history.**



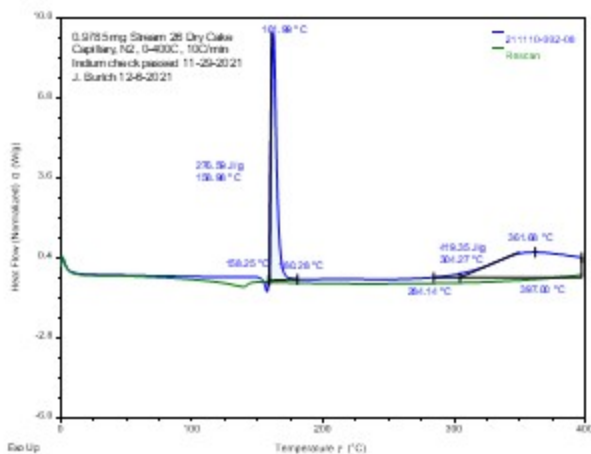
Reaction heat release kinetics of n^{th} -order reaction and autocatalytic reaction

(In all cases: Heat of reaction: -335 J/g, Activation Energy: 104.6 kJ/mol, Pre-exponential Factor: 28.4 s⁻¹)

Identification of Autocatalytic Reactions:

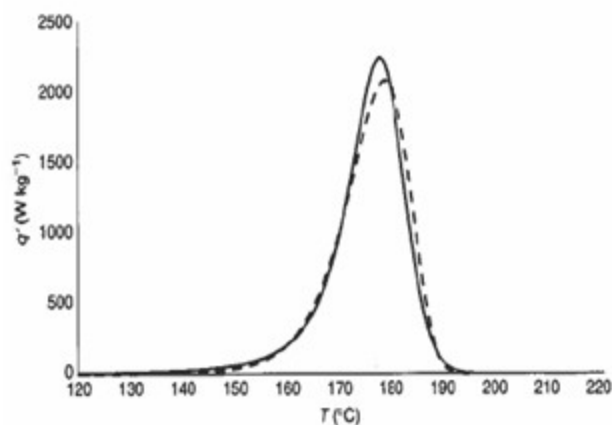
The differential scanning calorimeter (DSC) is an excellent tool that can be effectively used to screen for autocatalytic reactions.

DSC Dynamic Scan



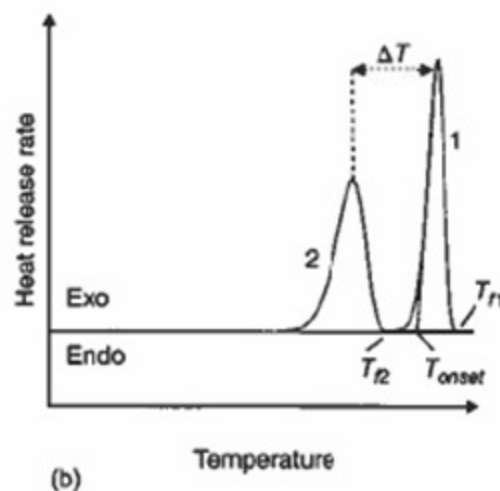
If **peak is tall and narrow** further investigation is warranted even if onset is well above the temperature the material will be exposed

Quick 1st order model



If apparent activation energy is ≥ 180 kJ/mol an autocatalytic reaction is likely.

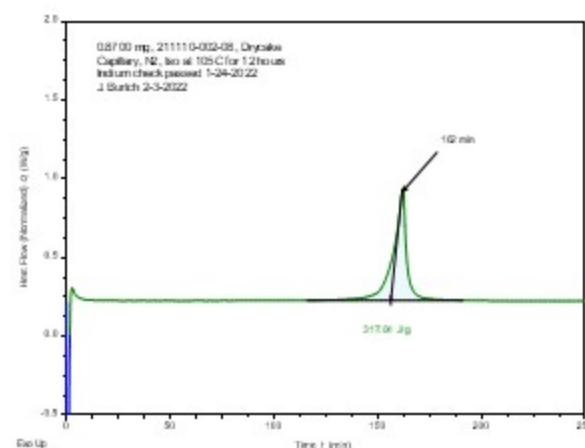
Double Scan Test



(b)

After aging, the DSC **peak** may be strongly shifted toward **lower temperatures**.

Isothermal DSC

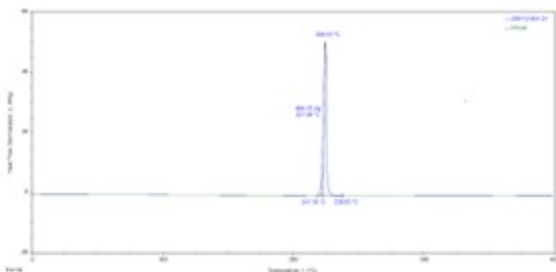


- Heat rate will pass through a **maximum** under isothermal conditions.
- **Most reliable method**
- Confirm autocatalytic

Identification of Autocatalytic Reactions:

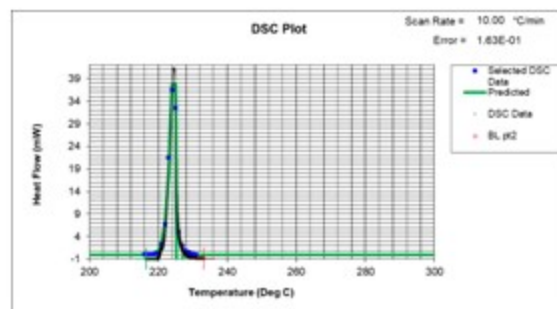
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DSC Dynamic Scan



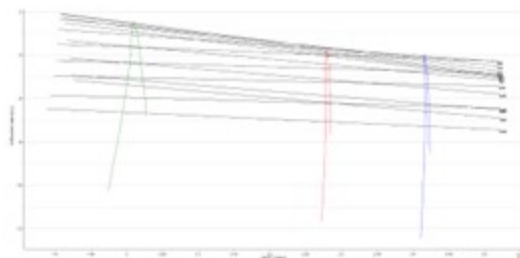
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Quick 1st order model



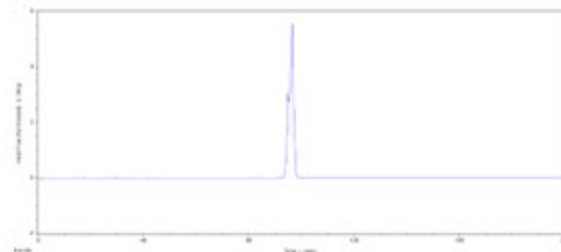
The apparent 1st order activation energy is **475 kJ/mol!**
An autocatalytic reaction is likely.

AKTS Modeling



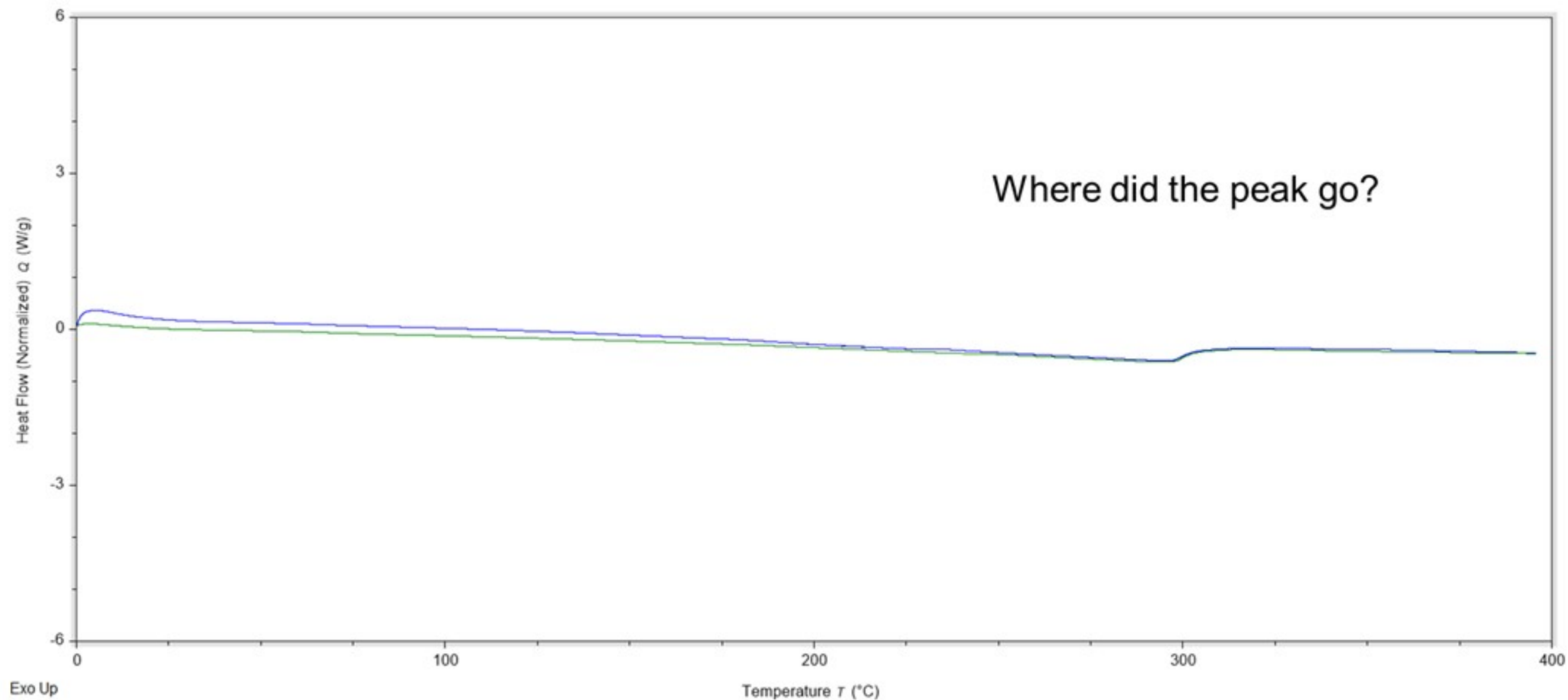
Can use thermokinetic conversion software to model dynamic scans to determine good isothermal temperature to test!

130°C Isothermal DSC



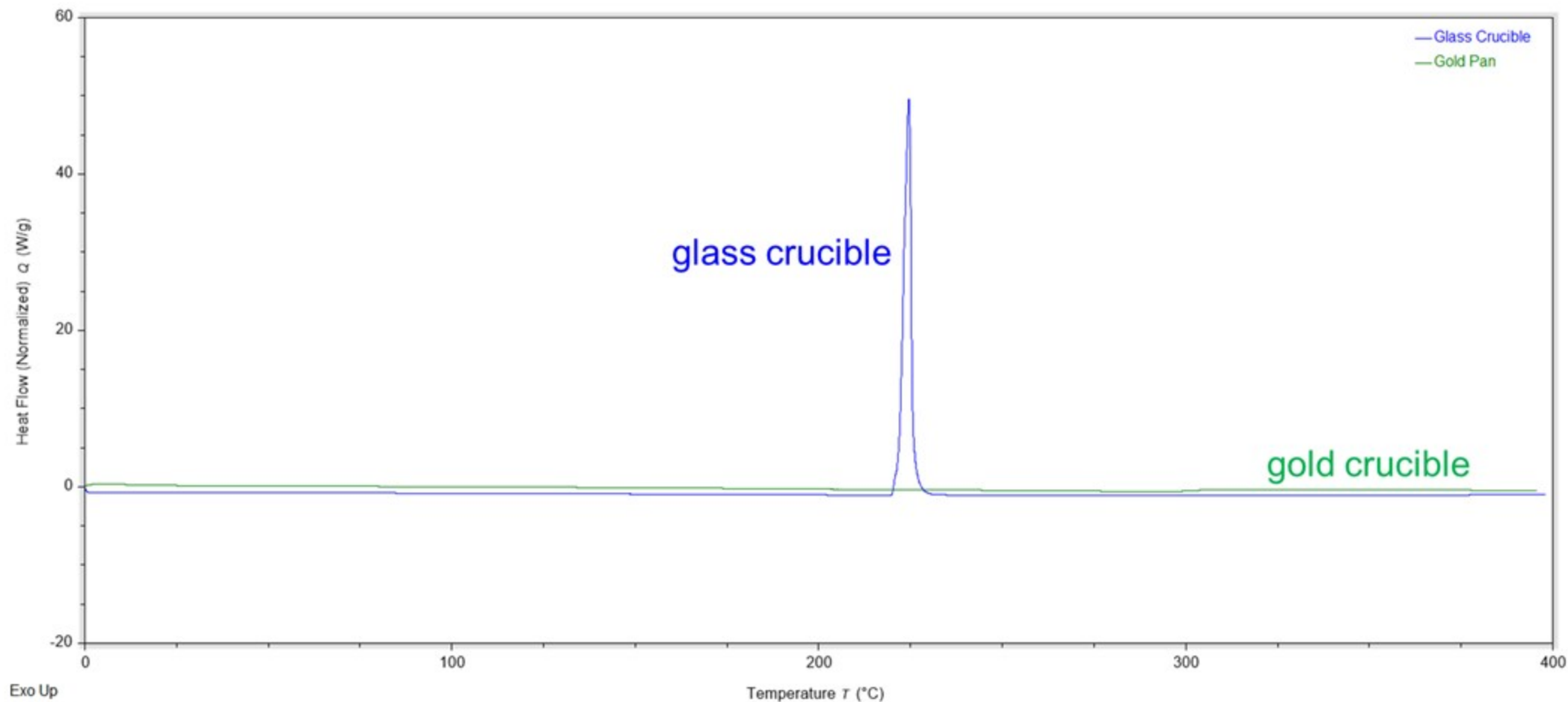
- Heat rate passed through a **maximum** under isothermal conditions.
- Confirmed autocatalytic

The story continues with another DSC test...



The story continues with another DSC test...

Unusual heat flow observed in DSC test with a glass DSC crucible



Materials Of Construction Issues

DSC Sample Pans

Sample container					
Container Material	Sealed glass capillary	Sealed glass ampoule	Gold Pan (SS gold plated)	Sealed Al pan	Al pan with pinhole
Max Pressure	200 barg	80 barg	200 barg	2 barg	0 barg
Cost per container	\$0.17	\$5.61	\$35.00	\$1.30	\$1.30
Reactivity Concerns	Strong bases, reactive fluorides (HF), silanes	Strong bases, reactive fluorides (HF), silanes	Strong acids (if not plated fully)	Oxidizers, acids, strong bases, halogenated cmpds, etc	Oxidizers, acids, strong bases, halogenated cmpds, etc

- **Inert High Pressure** DSC crucible is recommended by ASTM E537 for thermal stability hazard evaluation
 - This eliminates the use of aluminum pans for thermal stability testing
 - Need to consider other potential reactions that can occur with sample pans

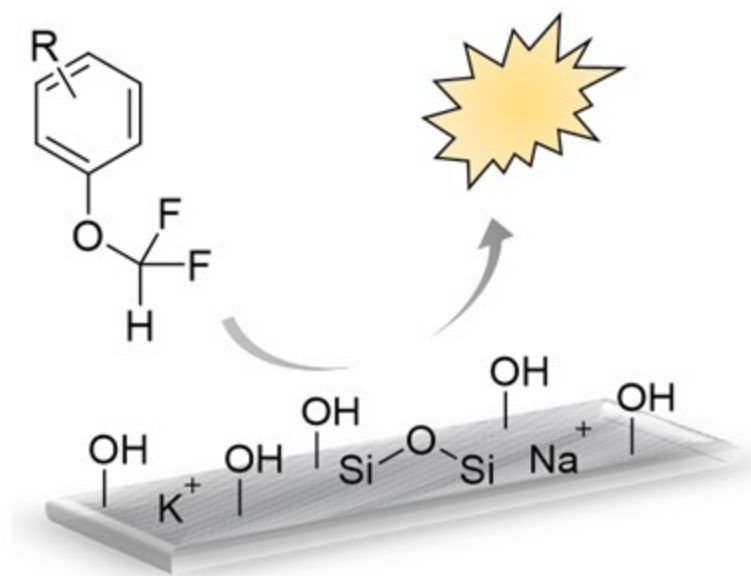
Why does this chemical react with glass?

A close look at its chemical structure

Glass is considered chemically inert but there are a few substances that can react with it:

- Hydrofluoric acid (HF)
- Strong bases
- Reactive fluoride species – chlorine trifluoride (ClF_3) and dioxygen difluoride (FOOF)
- Silane molecules ending with Si-O-Cl
- Difluoromethoxy compounds???

Based on the reactivity with glass, we identify that the difluoromethoxy functional group in the molecule potentially reacts with the glass via HF formation.



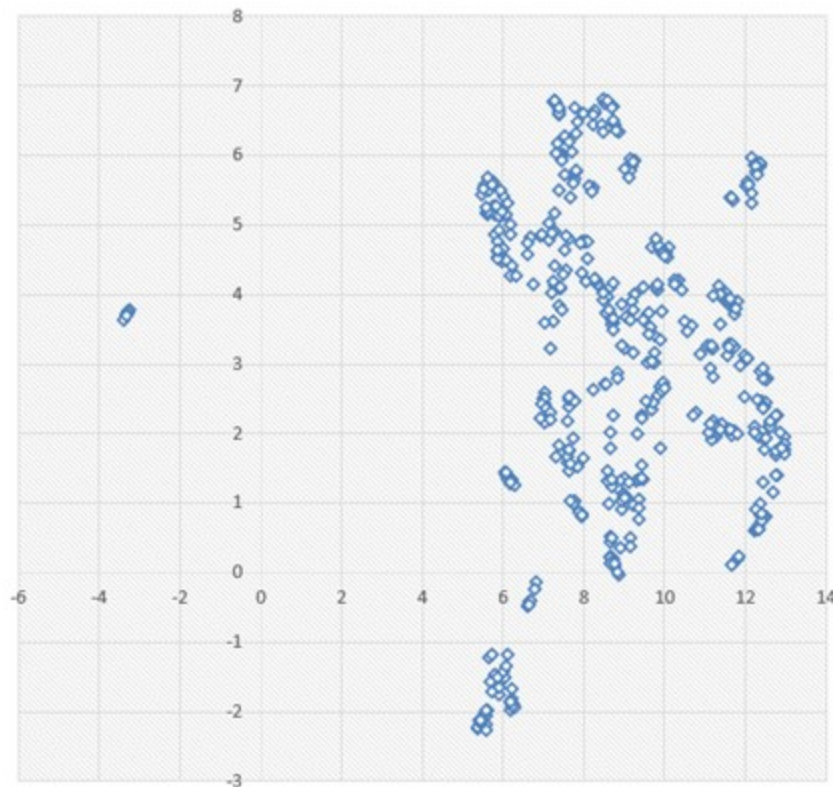
Understanding the question with computational approach

Is the difluoromethoxy group the one that reacts with glass?

- Manual testing is labor-intensive and impossible to cover every molecule.
- A more reasonable approach is to create a chemical space using computational techniques.
- Chemical space provides a framework for understanding the diversity of molecules. Then we pick molecules that cover the majority and are feasibly available.

Chemical space analysis

Is the difluoromethoxy group the one that reacts with glass?



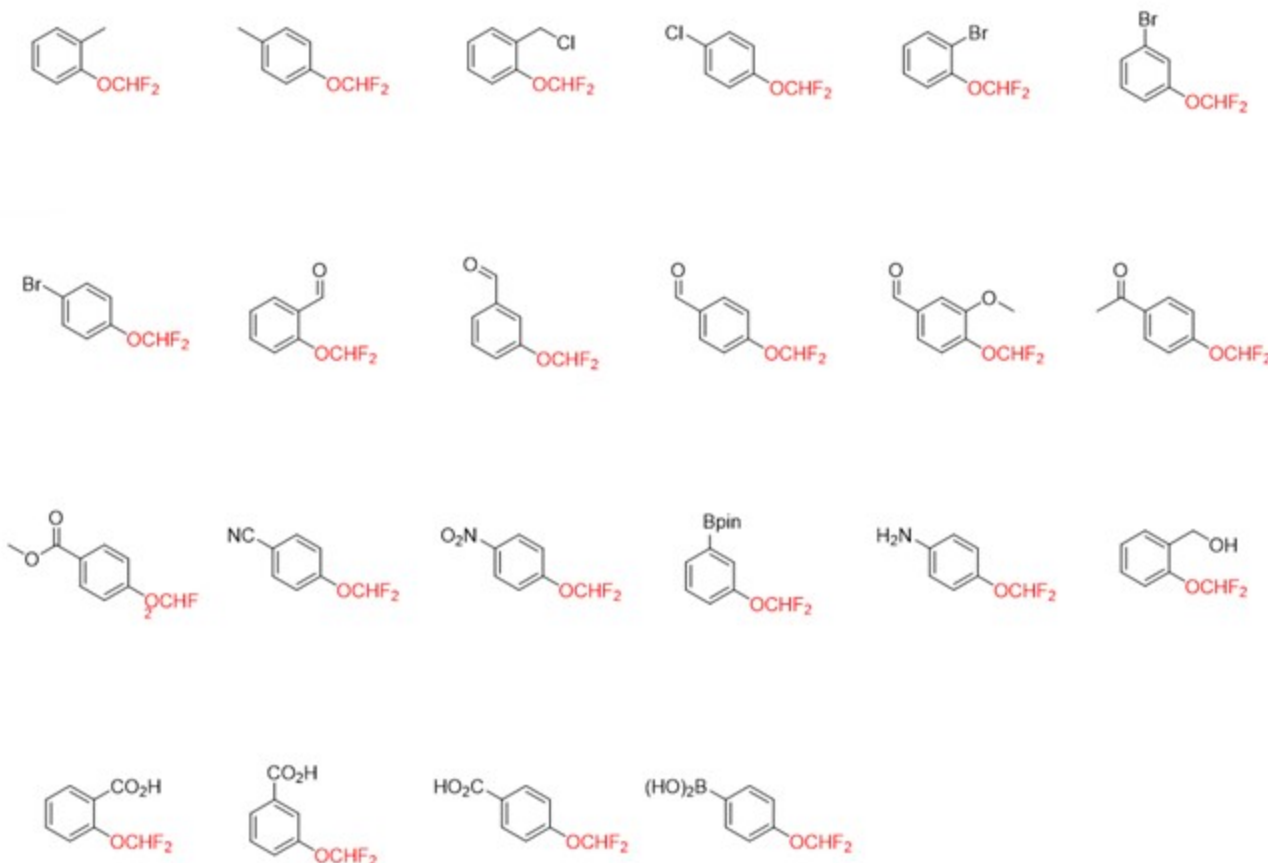
Procedure:

1. Select molecules that fill in the chemical space - top 500 molecules with aryl-OCHF₂ moiety ranked by the commercial availability (the number of suppliers in SciFinder).
2. Calculate molecular descriptors of these 500 molecules using Mordred (free and open-source software).
3. Create a chemical space map using the UMAP algorithm.

Understanding the question with experimental approach

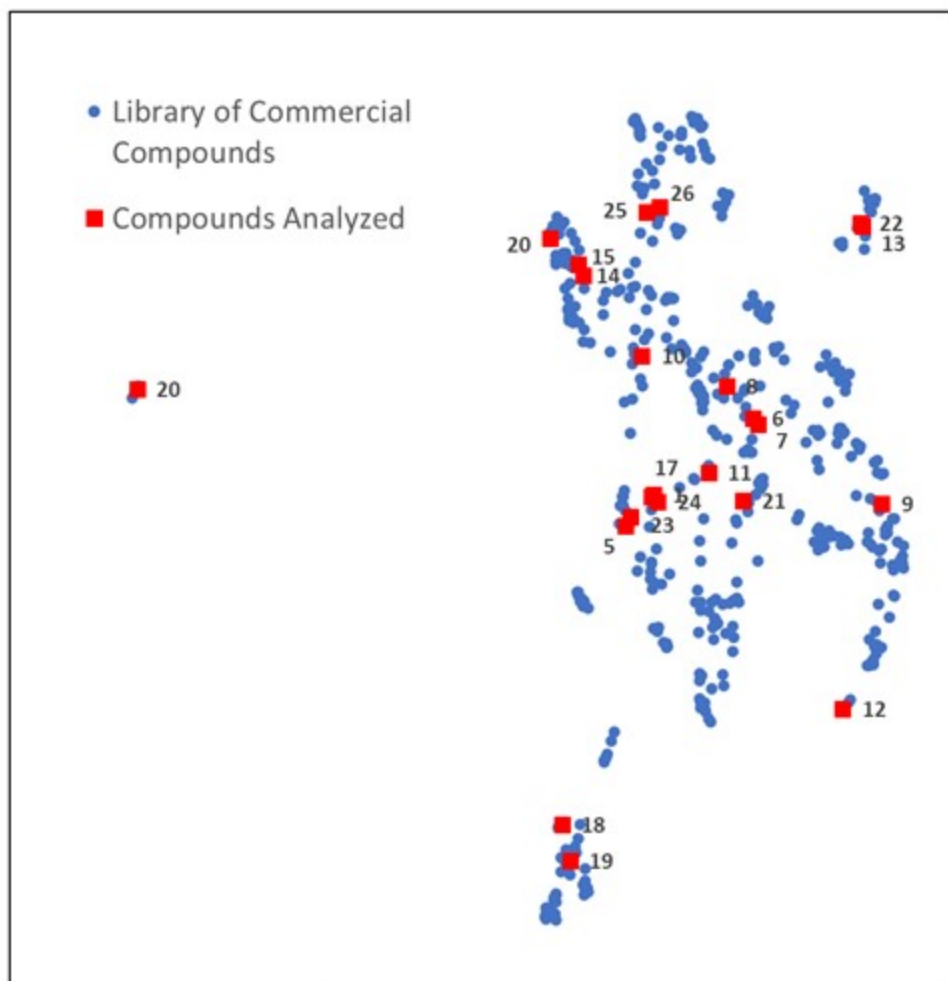
Is the difluoromethoxy group the moiety that reacts with glass?

- A library of molecules bearing the difluoromethoxy function group is investigated using DSC with a glass crucible.
- Most tested molecules show a tall and narrow exotherm peak, indicating a chemical reaction catalyzed by glass.
 - With the exception of 7, no exotherm noted up to 400C



Chemical space guided DSC tests

Is the difluoromethoxy group the one that reacts with glass?



The tested molecules are widely spread and cover the majority of the chemical space.

Most tested molecules show a very **tall and narrow exotherm** in DSC (maximum heat flow close to **80 W/g**) with a glass crucible, indicating the reaction between the chemical and glass materials.

Therefore, we have confidence that the chosen molecules are representative and that $-OCHF_2$ group and glass react and result in an aggressive exotherm.

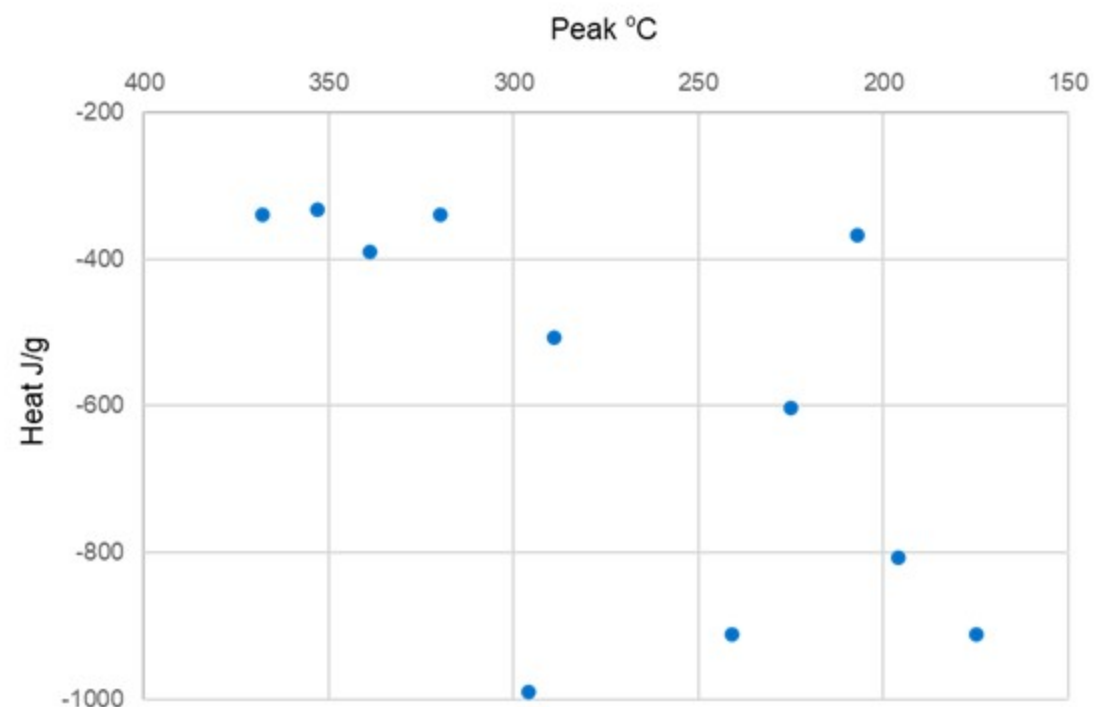
DSC results overview

Functionalization on difluoromethoxy benzene

Functional Group	Peak °C	Heat J/g
none	225	-602
2-methanol	175	-910.67
2-bromo	353	-332.85
3-bromo	320	-340.24
4-bromo	NA	Not observed
2-aldehyde	196	-806.29
2-methyl	289	-507.23

Functional Group	Peak °C	Heat J/g
3-aldehyde	296	-989.71
4-amine	241	-910.83
4-nitro	299	-1745*
4-chloro	339	-390.77
4-methyl acetate	368	-339.70
4-carboxylic acid	207	-368.08

*The heat contains two overlapped exotherm peaks, one of which belongs to nitrobenzene decomposition.

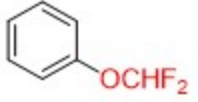
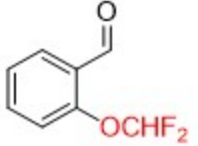
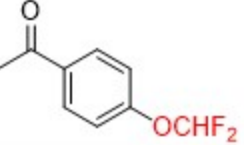
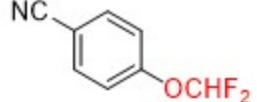
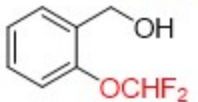
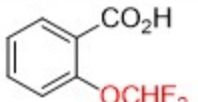


The functionalization influences the difluoromethoxy group reaction with glass, both at the scope of peak temperature and heat release.

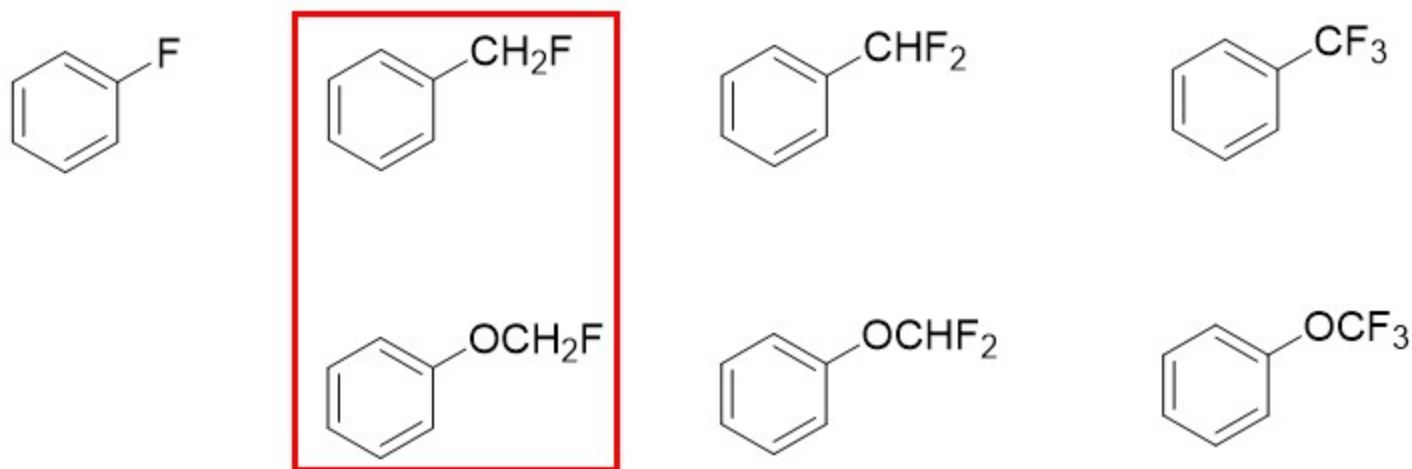
DSC Result Overview

Glass vs Gold Pan

- Exotherm is greatly catalyzed in the presence of glass
- Additional energy output is noted for the glass containers – indicating an additional reaction is occurring

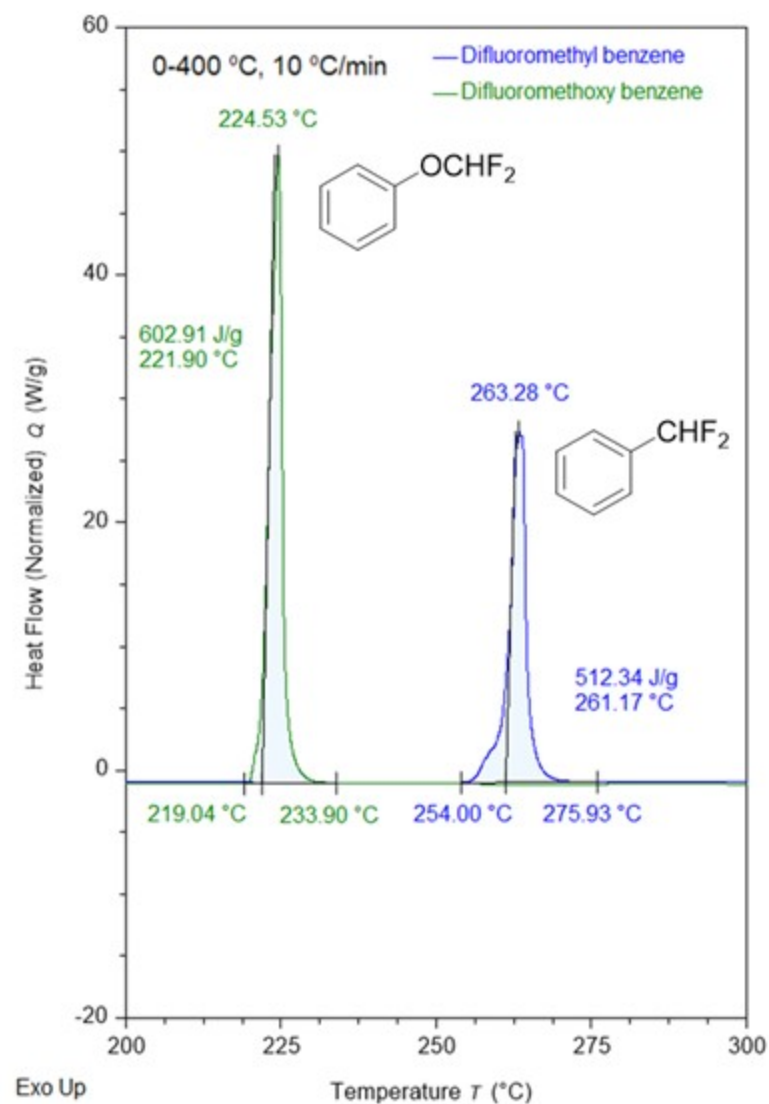
Sample Description	Glass		Gold	
	Peak Temperature (°C)	Heat (J/g)	Peak Temperature (°C)	Heat (J/g)
	225	-604.72	No exotherms observed up to 400 °C	
	196	-651.05	379	> -485.32
	237	-562.22	No exotherms observed up to 400 °C	
	292	-502.64	No exotherms observed up to 400 °C	
	175	-904.33	213	-548.55
	140	-447.74	No exotherms observed up to 400 °C	

Should we be concerned about all aryl-fluorinated molecules?



Not examined due to commercial infeasibility

- Except for difluoromethoxy benzene and difluoromethyl benzene, all other molecules tested showed no major exotherms up to 400 °C in DSC tests.



Materials Of Construction Issues

Corrosion Issues vs Reactive Chemicals Issue

Corrosion Issue vs Reactive Chemicals Issue

Corrosion damage is not instantaneous, unlike RC, and the effect is generally not dangerous

Corrosion can be a result of incompatibility (not-so-compatible) of materials of construction to process chemistry (materials-chemistry interaction).

Glass or metals acting as a catalyst to decomposition can fall under both RC as well as Corrosion, because here materials of construction-chemistry interactions is taking place.



Summary

- We identified a chemical that undergoes autocatalytic thermal decomposition as well as reaction with glass that facilitates its thermal decomposition.
- The computational method-assisted study validated the universal interaction between chemicals bearing difluoromethoxy (-OCHF₂) group and glass.
- A hypothetical reaction mechanism and catalytic cycle were proposed.
- Using a glass DSC crucible sometimes identifies the thermal hazard that might be overlooked when using a gold DSC crucible, especially if the reaction is executed in a glass reactor.
 - Good to ensure materials of construction do not create an unforeseen RC hazard!

Acknowledgements

- Sirun Yang
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THANK YOU

QUESTIONS?