Chemical Process Development Using JMP: Elucidating Chemical Mechanisms with Statistics

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INTRODUCTION

Background

Novomer, Inc. is commercializing a class of aliphatic polycarbonate polyols that use carbon dioxide as a raw material in their synthesis.

The key to the technology is the catalyst, which incorporates CO_2 directly into the polymer backbone, providing materials with up to 50 wt% CO_2 in the product. This CO_2 is permanently fixed into the molecule, providing one of the only ways that waste CO_2 can be incorporated into new chemicals while utilizing 100% of its mass.

A New Catalyst

Novomer developed a new catalyst that showed much improved activity and selectivity when compared to the original catalyst. We wanted to advance the process development as fast as possible, but this catalyst was significantly different than our first generation catalyst. We worked with JMP to incorporate a new type of screening design – the Definitive Screening Design.

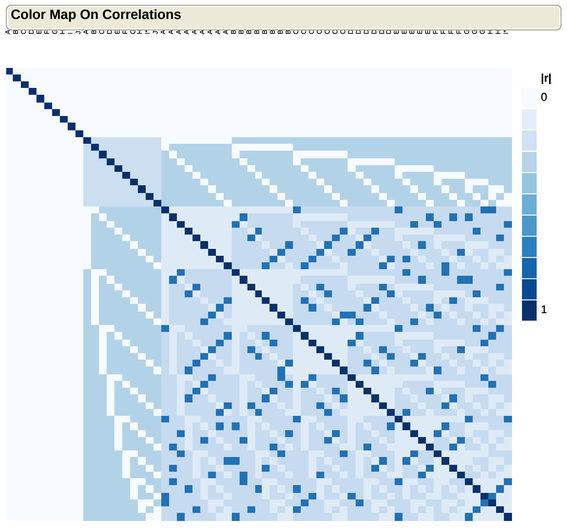
METHOD

Definitive Screening Design

The definitive screening design is a new type of design that provides a number of benefits when screening a large number of factors. The desirability of this design over classic partial factorial designs are due to several key features:[1]

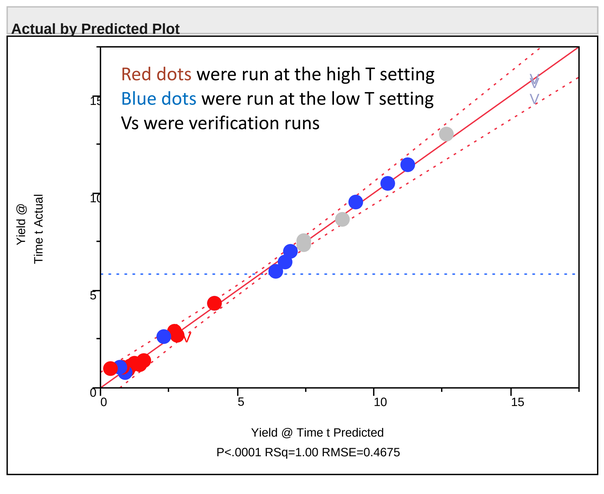
- Two-factor and quadratic interactions are uncorrelated with main effects
- All quadratic effects are estimable
- Linear relationship between factors and number of reactions: 2n+1 experiments

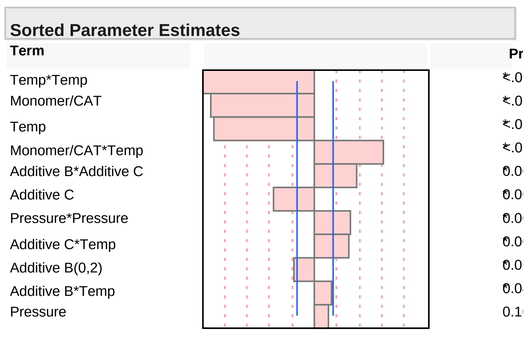
The design we used evaluated 10 factors in 21 reactions. The responses were reaction yield, product selectivity and product molecular weight. The resulting color map of factor correlations is shown to the right.



RESULTS

Predictive Model and Identification of Significant Factors



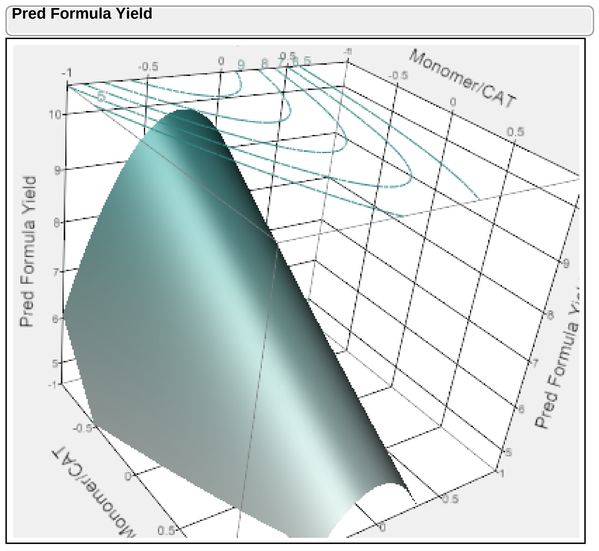


Temperature squared is the most significant factor for predicting polymerization yield.

- *What does this mean mechanistically?*
- *Can we gain any insight into the chemistry?*

RESULTS (CONTINUED)

A Closer Look at the Temperature Factor



An optimal temperature was discovered

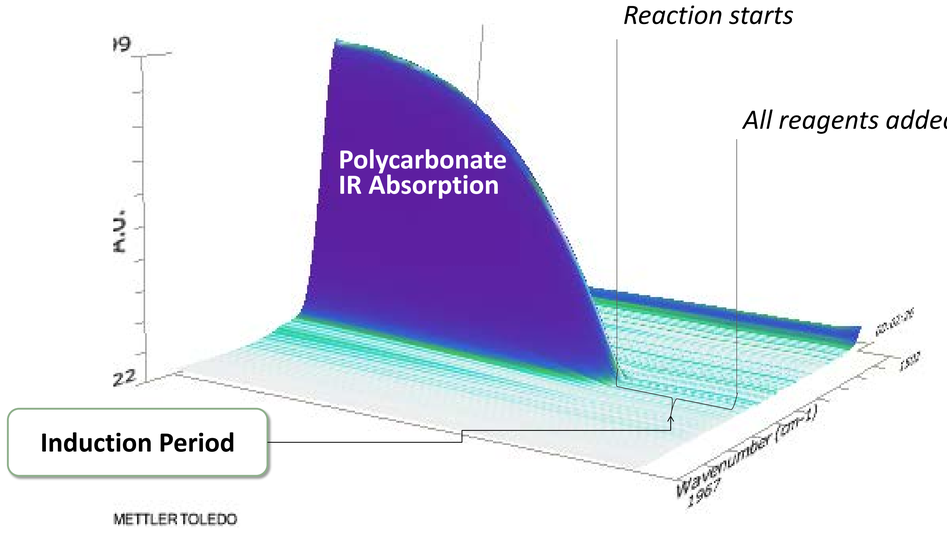
From a mechanistic standpoint, we wanted to determine what was happening at the lower and upper temperatures that would cause the reaction to slow down?

High temperature: Loss of selectivity leads to lower over-all yields.

Low temperature: The loss in activity is much more than expected based on simple kinetics.

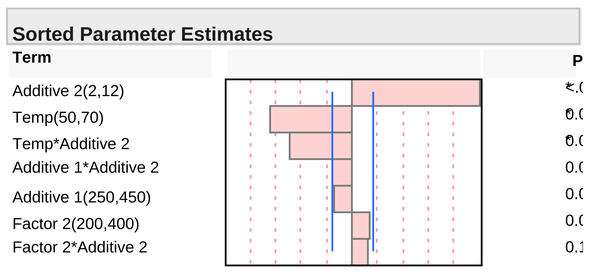
Is there a secondary effect?

In Situ Infrared Spectroscopy



In situ infrared spectroscopy revealed that an induction period exists with this new catalyst system. This was unexpected and varied significantly from reaction to reaction. Since the definitive screening design had a constant reaction time, if the induction period varied, the resulting polymer yield would vary unpredictably.

Partial Factorial Design to Determine Factors Influencing Induction Period



Induction period was modeled as a function of four factors. As seen in the Sorted Parameter Estimates, an additive in the system dominated the magnitude of the induction period, but Temperature was a major factor. This follow-up design showed us that the induction period contributed to the temperature squared term in the original screening design.

CONCLUSIONS

A definitive screening design was carried out on a new catalyst system to efficiently determine main effects. The design revealed an unexpected polynomial term on the effect of temperature. The mechanistic significance of this polynomial term was elucidated through a follow-up partial factorial design.

REFERENCES

[1] Jones, B.; Nachtsheim, C., *Journal of Quality Technology*, **2011**, *43*, 1-15.

ACKNOWLEDGEMENTS

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