Syam Evani, Project 1

Part 1

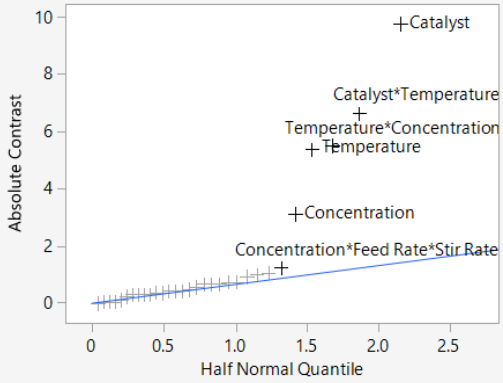
Recreating the JMP analysis for the reactor runs, I generated the screening report and half normal plot below

Screening for Percent Reacted

Contrasts

Term	Contrast	Lenth t-Ratio	Individual p-Value	Simultaneous p-Value
Catalyst	9.75000	14.86	<.0001*	<.0001*
Temperature	5.37500	8.19	<.0001*	0.0007*
Concentration	-3.12500	-4.76	0.0012*	0.0186*
Feed Rate	-0.68750	-1.05	0.2902	0.9999
Stir Rate	-0.31250	-0.48	0.6482	1.0000
Catalyst*Temperature	6.62500	10.10	<.0001*	0.0002*
Catalyst*Concentration	1.00000	1.52	0.1330	0.9541
Temperature*Concentration	-5.50000	-8.38	<.0001*	0.0007*
Catalyst*Feed Rate	0.68750	1.05	0.2902	0.9999
Temperature*Feed Rate	-0.43750	-0.67	0.5032	1.0000
Concentration*Feed Rate	0.06250	0.10	0.9277	1.0000
Catalyst*Stir Rate	0.43750	0.67	0.5256	1.0000
Temperature*Stir Rate	1.06250	1.62	0.1115	0.9211
Concentration*Stir Rate	0.43750	0.67	0.5032	1.0000
Feed Rate*Stir Rate	0.37500	0.57	0.5881	1.0000
Catalyst*Temperature*Concentration	-0.12500	-0.19	0.8585	1.0000
Catalyst*Temperature*Feed Rate	0.68750	1.05	0.2902	0.9999
Catalyst*Concentration*Feed Rate	-0.93750	-1.43	0.1593	0.9757
Temperature*Concentration*Feed Rate	0.31250	0.48	0.6482	1.0000
Catalyst*Temperature*Stir Rate	0.56250	0.86	0.3845	1.0000
Catalyst*Concentration*Stir Rate	0.06250	0.10	0.9277	1.0000
Temperature*Concentration*Stir Rate	0.06250	0.10	0.9277	1.0000
Catalyst*Feed Rate*Stir Rate	0.75000	1.14	0.2531	0.9990
Temperature*Feed Rate*Stir Rate	-0.37500	-0.57	0.5881	1.0000
Concentration*Feed Rate*Stir Rate	-1.25000	-1.90	0.0676	0.7619
Catalyst*Temperature*Concentration*Feed Rate	0.31250	0.48	0.6482	1.0000
Catalyst*Temperature*Concentration*Stir Rate	-0.31250	-0.48	0.6482	1.0000
Catalyst*Temperature*Feed Rate*Stir Rate	0.00000	0.00	1.0000	1.0000
Catalyst*Concentration*Feed Rate*Stir Rate	0.75000	1.14	0.2531	0.9990
Temperature*Concentration*Feed Rate*Stir Rate	0.50000	0.76	0.4401	1.0000
Catalyst*Temperature*Concentration*Feed Rate*Stir Rate	-0.25000	-0.38	0.7160	1.0000

Half Normal Plot



Lenth PSE=0.65625

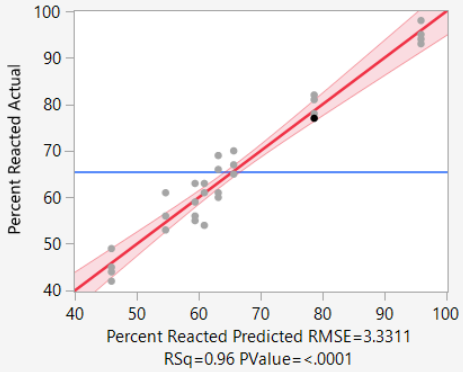
P-Values derived from a simulation of 10000 Lenth t ratios.

Make Model | Run Model

Examining the predictions I get the following:

Response Percent Reacted

Actual by Predicted Plot



Effect Summary

Source	Logworth	PValue
Catalyst(1,2)	14.602	0.00000
Catalyst*Temperature	10.763	0.00000
Temperature*Concentration	9.065	0.00000
Temperature(140,180)	8.864	0.00000 ^
Concentration(3,6)	4.825	0.00001 ^

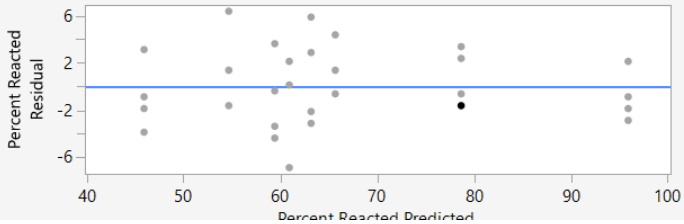
Remove Add Edit Exclude ☐ FDR

('^' denotes effects with containing effects above them)

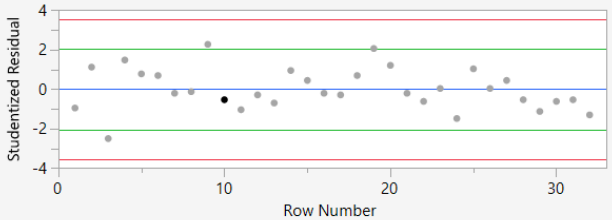
Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	2	32.50000	16.2500	1.5234
Pure Error	24	256.00000	10.6667	**Prob > F**
Total Error	26	288.50000		0.2383
				Max RSq
				0.9631

Residual by Predicted Plot



Studentized Residuals



Externally studentized residuals with 95% simultaneous limits (Bonferroni) in red, individual limits in green.

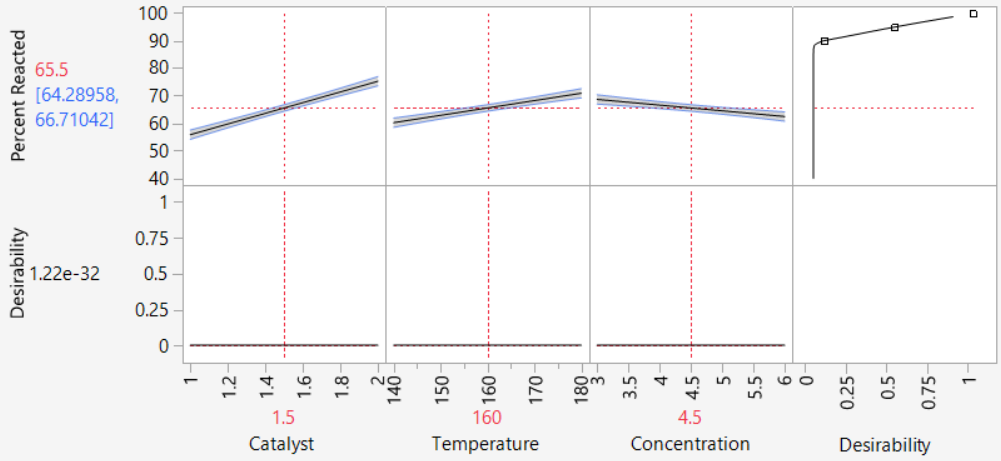
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	Uncoded Estimate
Intercept	65.5	0.588859	111.23	<.0001*	29.625
Catalyst(1,2)	9.75	0.588859	16.56	<.0001*	-86.5
Temperature(140,180)	5.375	0.588859	9.13	<.0001*	0.1
Concentration(3,6)	-3.125	0.588859	-5.31	<.0001*	27.25
Catalyst*Temperature	6.625	0.588859	11.25	<.0001*	0.6625
Temperature*Concentration	-5.5	0.588859	-9.34	<.0001*	-0.183333

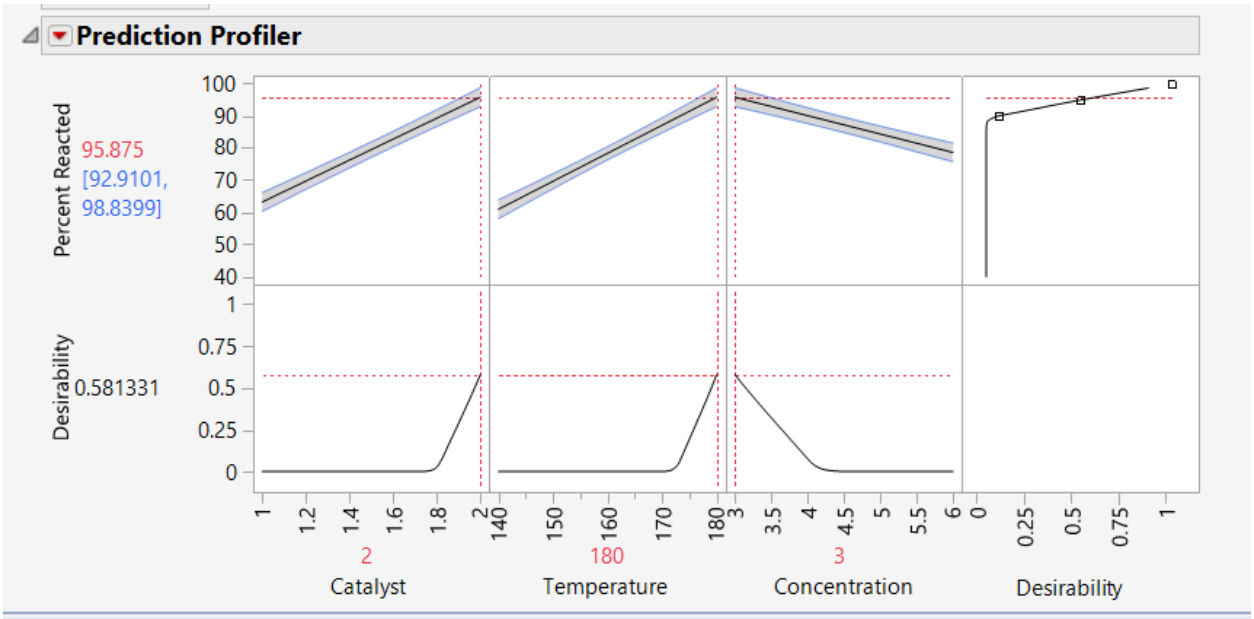
Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Catalyst(1,2)	1	1	3042.0000	274.1490	<.0001*
Temperature(140,180)	1	1	924.5000	83.3172	<.0001*
Concentration(3,6)	1	1	312.5000	28.1629	<.0001*
Catalyst*Temperature	1	1	1404.5000	126.5754	<.0001*
Temperature*Concentration	1	1	968.0000	87.2374	<.0001*

Prediction Profiler



Finally we can create a reduced order model experiment, then optimize for desirability with the prediction profiler. I get a response like this. This really indicates that maximizing the catalyst, temperature, and minimizing the concentration will maximize desirability.



Part 2, 3, and 4 (Python and Discussion)

My code for this can be found here as well on this public Github: https://github.com/Sam-v6/mece-6397-doe/tree/main/project1

Importing Modules

For starters I import pandas, numpy, and combonations which helps generate all possible combos to examine interactions of different factors.

In [ ]:
```
"""
Purpose: Project 1 - Driver script for factorial design and main effects calculatio
Author: Syam Evani
"""

# Standard imports
import os

# Additional imports
import pandas as pd
import numpy as np
from itertools import combinations

# Local imports
# None
```

Creating the design

To create the design I define 2 levels (a low and high) and 5 factors which matches the JMP simulation that we did in the prior section. Notice that for our factors I defined a low and high value similar to that of the jmp simulation.

I generate the experiment design, which at this point is just 0 or 1s indicating low or highs. I save the history of each design into the "pattern" to ultimately display that in the final design output, similar to that of the JMP simulation. I then translate these low and high boolean values into the actual minimum or maximum values specific to the factor itself (for example feed rate low is 10 and high is 15).

I then create a fictional response that we call the "percent reacted" using random number generation.

In [ ]:
```
#-----------------------------------------------------------------------
# DOE Design Section
#-----------------------------------------------------------------------
# Define factors and their levels
```

```
levels = [0, 1]  # Assuming -1 is low, 0 is medium, and +1 is high
factors={
        'Feed Rate': {"Min": 10, "Max": 15},
        'Catalyst':{"Min": 1, "Max": 2},
        'Stir Rate':{"Min": 100, "Max": 120},
        'Temperature':{"Min": 140, "Max": 180},
        'Concentration':{"Min": 3, "Max": 6}
        }

# Generate full factorial design
experiment_design = pd.DataFrame(np.array(np.meshgrid(levels, levels, levels, level

# Capture what pattern was generated
pattern_list = []
for i in range(0,32):
    pattern = []
    for factor in experiment_design.columns:
        pattern.append(experiment_design[factor][i])
    pattern_list.append(pattern)

# Map the levels to their corresponding min and max values
for factor in experiment_design.columns:
    for i in range(0,32):
        if experiment_design[factor][i] == 0:
            experiment_design[factor][i] = factors[factor]["Min"]
        else:
            experiment_design[factor][i] = factors[factor]["Max"]

# Add the pattern and percent reacted to the design
experiment_design['Pattern'] = pattern_list

# Display the design with percent reacted
np.random.seed(42)  # For reproducibility
experiment_design['Percent Reacted'] = np.random.rand(len(experiment_design))*100
```

Main Effects Calculation

Similar to the main effects calculation in the provided code, I simply group the factors and evalute the mean for percent reacted to see how each factor plays into impacting overall percent reacted.

In [ ]:

```
#-----------------------------------------------------------------------
# DOE Main Effects Calculation
#-----------------------------------------------------------------------
main_effects = {}
for factor in factors.keys():
    main_effects[factor] = experiment_design.groupby(factor)['Percent Reacted'].mea
```

Interaction Effects Calculation

To calculate the interactions effects I generate all combonations of the factors (from 2 factors out to 5 factors). I then can similarly group these combonations of factors and evalute the mean of percent reacted to see the interaction effects.

In [ ]:
```
#----------------------------------------------------------------------
## DOE Interaction Effects Calculation
#----------------------------------------------------------------------
# Calculate interaction effects
interaction_effects = {}
factor_names = list(factors.keys())
for r in range(2, len(factor_names) + 1):
    for combo in combinations(factor_names, r):
        interaction_term = ' x '.join(combo)
        interaction_effects[interaction_term] = experiment_design.groupby(list(comb
```

Creating contrast and printing

Similar to the JMP simulation, I want to evaluate the "contrast", which effectively is which direction does it drive the mean of percent reacted. This can be determined by determining the difference between the mean associated with the low and high level of either the main factor or combonation of factors.

I then can sort the contrast from most impactful (positively impact percent reacted) to least impactful and output/print this text file to see the full rankings to determine which factors or combonations will be best to increase percent reacted.

In [ ]:
```
#----------------------------------------------------------------------
# Generate Contrast Output
#----------------------------------------------------------------------
contrast_output = pd.DataFrame(columns=['Factor/Interaction', 'Low Level Mean', 'Hi
contrast_rows = []

# Calculate contrast for main effects
for factor in factors.keys():
    low_level_mean = main_effects[factor].iloc[0]
    high_level_mean = main_effects[factor].iloc[1]
    effect = high_level_mean - low_level_mean
    contrast_rows.append({
        'Factor/Interaction': factor,
        'Low Level Mean': low_level_mean,
        'High Level Mean': high_level_mean,
        'Effect': effect
    })

# Calculate contrast for interaction effects
for interaction_term, interaction_data in interaction_effects.items():
    for idx, (level, row) in enumerate(interaction_data.iterrows()):
        low_level_mean = row.iloc[0]
        high_level_mean = row.iloc[1]
        effect = high_level_mean - low_level_mean
        contrast_rows.append({
```

```
            'Factor/Interaction': f'{interaction_term} (Level {level})',
            'Low Level Mean': low_level_mean,
            'High Level Mean': high_level_mean,
            'Effect': effect
        })

# Save contrast and sort from highest to lowest
contrast_output = pd.DataFrame(contrast_rows)
contrast_output = contrast_output.sort_values(by='Effect', ascending=False)
```

In [ ]:

```
#-----------------------------------------------------------------------
# Print design, main effects contrast, and overall constrast rankings
#-----------------------------------------------------------------------
# Print design
print("Full Factorial Design and Percent Reacted:")
print(experiment_design)

# Print main effects constrast
print("\nMain Effects:")
for factor, effects in main_effects.items():
    print(f"\n{factor}:")
    print(effects)

# Save contrast to text file for interactions
with open(os.path.join(os.getenv('USERPROFILE'),"repos","mece-6397-doe","project1",
    file.write(contrast_output.to_string(index=False))

# Print overall rankings
with open(os.path.join(os.getenv('USERPROFILE'),"repos","mece-6397-doe","project1",
    contents = file.read()

print(contents)
```

Full Factorial Design and Percent Reacted:

	Feed Rate	Catalyst	Stir Rate	Temperature	Concentration
0	10	1	100	140	3
1	10	2	100	140	3
2	15	1	100	140	3
3	15	2	100	140	3
4	10	1	120	140	3
5	10	2	120	140	3
6	15	1	120	140	3
7	15	2	120	140	3
8	10	1	100	180	3
9	10	2	100	180	3
10	15	1	100	180	3
11	15	2	100	180	3
12	10	1	120	180	3
13	10	2	120	180	3
14	15	1	120	180	3
15	15	2	120	180	3
16	10	1	100	140	6
17	10	2	100	140	6
18	15	1	100	140	6
19	15	2	100	140	6
20	10	1	120	140	6
21	10	2	120	140	6
22	15	1	120	140	6
23	15	2	120	140	6
24	10	1	100	180	6
25	10	2	100	180	6
26	15	1	100	180	6
27	15	2	100	180	6
28	10	1	120	180	6
29	10	2	120	180	6
30	15	1	120	180	6
31	15	2	120	180	6

	Pattern	Percent Reacted
0	[0, 0, 0, 0, 0]	37.454012
1	[0, 1, 0, 0, 0]	95.071431
2	[1, 0, 0, 0, 0]	73.199394
3	[1, 1, 0, 0, 0]	59.865848
4	[0, 0, 1, 0, 0]	15.601864
5	[0, 1, 1, 0, 0]	15.599452
6	[1, 0, 1, 0, 0]	5.808361
7	[1, 1, 1, 0, 0]	86.617615
8	[0, 0, 0, 1, 0]	60.111501
9	[0, 1, 0, 1, 0]	70.807258
10	[1, 0, 0, 1, 0]	2.058449
11	[1, 1, 0, 1, 0]	96.990985
12	[0, 0, 1, 1, 0]	83.244264
13	[0, 1, 1, 1, 0]	21.233911
14	[1, 0, 1, 1, 0]	18.182497
15	[1, 1, 1, 1, 0]	18.340451
16	[0, 0, 0, 0, 1]	30.424224
17	[0, 1, 0, 0, 1]	52.475643
18	[1, 0, 0, 0, 1]	43.194502
19	[1, 1, 0, 0, 1]	29.122914

```
20  [0, 0, 1, 0, 1]        61.185289
21  [0, 1, 1, 0, 1]        13.949386
22  [1, 0, 1, 0, 1]        29.214465
23  [1, 1, 1, 0, 1]        36.636184
24  [0, 0, 0, 1, 1]        45.606998
25  [0, 1, 0, 1, 1]        78.517596
26  [1, 0, 0, 1, 1]        19.967378
27  [1, 1, 0, 1, 1]        51.423444
28  [0, 0, 1, 1, 1]        59.241457
29  [0, 1, 1, 1, 1]         4.645041
30  [1, 0, 1, 1, 1]        60.754485
31  [1, 1, 1, 1, 1]        17.052412

Main Effects:

Feed Rate:
Feed Rate
10    46.573083
15    40.526837
Name: Percent Reacted, dtype: float64

Catalyst:
Catalyst
1    40.328071
2    46.771848
Name: Percent Reacted, dtype: float64

Stir Rate:
Stir Rate
100    52.893224
120    34.206696
Name: Percent Reacted, dtype: float64

Temperature:
Temperature
140    42.838787
180    44.261133
Name: Percent Reacted, dtype: float64

Concentration:
Concentration
3    47.511706
6    39.588214
Name: Percent Reacted, dtype: float64
                                                                                Factor/Interac
tion  Low Level Mean  High Level Mean     Effect
Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (10, 1, 120, 1
40))       15.601864        61.185289  45.583425
Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (15, 1, 120, 1
80))       18.182497        60.754485  42.571988
               Catalyst x Stir Rate x Temperature x Concentration (Level (1, 120, 1
40))       10.705113        45.199877  34.494765
                  Feed Rate x Catalyst x Stir Rate x Concentration (Level (15, 1, 1
20))       11.995429        44.984475  32.989046
                    Feed Rate x Catalyst x Stir Rate x Temperature (Level (10, 1, 1
20))       38.393577        71.242860  32.849284
```

```
                  Feed Rate x Catalyst x Temperature x Concentration (Level (15, 1, 1
80))       10.120473        40.360932  30.240459
                     Feed Rate x Catalyst x Stir Rate x Temperature (Level (15, 2, 1
00))       44.494381        74.207215  29.712833
                                  Catalyst x Stir Rate x Temperature (Level (1, 1
20))       27.952495        55.355676  27.403181
                                   Feed Rate x Catalyst x Temperature (Level (10,
1))       36.166347        62.051055  25.884708
Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (15, 1, 120, 1
40))        5.808361        29.214465  23.406104
               Feed Rate x Stir Rate x Temperature x Concentration (Level (10, 120, 1
40))       15.600658        37.567338  21.966680
                     Feed Rate x Catalyst x Stir Rate x Temperature (Level (15, 1, 1
20))       17.511413        39.468491  21.957078
                            Catalyst x Stir Rate x Concentration (Level (1, 1
20))       30.709247        52.598924  21.889678
               Feed Rate x Stir Rate x Temperature x Concentration (Level (15, 120, 1
80))       18.261474        38.903449  20.641975
                  Feed Rate x Catalyst x Temperature x Concentration (Level (10, 1, 1
40))       26.527938        45.804757  19.276819
                     Feed Rate x Catalyst x Stir Rate x Temperature (Level (10, 1, 1
00))       33.939118        52.859250  18.920132
                                                  Feed Rate x Catalyst (Level
15)       31.547441        49.506232  17.958790
Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (15, 1, 100, 1
80))        2.058449        19.967378  17.908929
                            Feed Rate x Stir Rate x Temperature (Level (10, 1
20))       26.583998        42.091168  15.507170
                             Catalyst x Stir Rate x Temperature (Level (2, 1
00))       59.133959        74.434821  15.300862
                           Feed Rate x Catalyst x Concentration (Level (15,
1))       24.812175        38.282708  13.470532
                                               Feed Rate x Temperature (Level
10)       40.220163        52.926003  12.705841
                                 Feed Rate x Catalyst x Stir Rate (Level (10,
1))       43.399184        54.818219  11.419035
                    Feed Rate x Catalyst x Stir Rate x Concentration (Level (10, 1, 1
20))       49.423064        60.213373  10.790309
                            Feed Rate x Stir Rate x Temperature (Level (10, 1
00))       53.856327        63.760838   9.904511
                 Catalyst x Stir Rate x Temperature x Concentration (Level (1, 120, 1
80))       50.713380        59.997971   9.284591
                           Catalyst x Temperature x Concentration (Level (1, 1
40))       33.015908        41.004620   7.988712
Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (10, 2, 100, 1
80))       70.807258        78.517596   7.710338
                                               Catalyst x Concentration (Leve
l 1)       36.957543        43.698600   6.741057
                                                 Catalyst x Temperature (Leve
l 1)       37.010264        43.645879   6.635615
                                                                        Cata
lyst       40.328071        46.771848   6.443777
                           Catalyst x Temperature x Concentration (Level (1, 1
80))       40.899178        46.392580   5.493402
                             Stir Rate x Temperature x Concentration (Level (120, 1
40))       30.906823        35.246331   4.339508
```

```
                                  Feed Rate x Stir Rate x Concentration (Level (15, 1
20))       32.237231        35.914387   3.677156
                                Feed Rate x Temperature x Concentration (Level (15, 1
80))       33.893096        37.299430   3.406334
                                                      Catalyst x Stir Rate (Leve
l 1)       39.002057        41.654085   2.652028
                                                 Stir Rate x Temperature (Level
120)       33.076577        35.336815   2.260238
                                                Stir Rate x Concentration (Level
120)       33.078552        35.334840   2.256288
                     Catalyst x Stir Rate x Temperature x Concentration (Level (1, 100, 1
80))       31.084975        32.787188   1.702213
                                                                          Tempera
ture       42.838787        44.261133   1.422346
                          Feed Rate x Catalyst x Stir Rate x Temperature (Level (10, 2, 1
00))       73.773537        74.662427   0.888890
                                Feed Rate x Stir Rate x Concentration (Level (10, 1
20))       33.919873        34.755293   0.835421
                                                 Stir Rate x Temperature (Level
100)       52.600996        53.185451   0.584455
                               Stir Rate x Temperature x Concentration (Level (120, 1
80))       35.250281        35.423349   0.173068
                                       Feed Rate x Catalyst x Concentration (Level (10,
1))       49.102910        49.114492   0.011582
                                         Feed Rate x Catalyst x Temperature (Level (10,
2))       44.273978        43.800952  -0.473026
Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (15, 2, 120, 1
80))       18.340451        17.052412  -1.288039
                                Feed Rate x Temperature x Concentration (Level (10, 1
40))       40.931690        39.508636  -1.423054
Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (10, 2, 120, 1
40))       15.599452        13.949386  -1.650066
                          Feed Rate x Catalyst x Stir Rate x Temperature (Level (10, 2, 1
20))       14.774419        12.939476  -1.834943
                       Feed Rate x Catalyst x Temperature x Concentration (Level (15, 1, 1
40))       39.503878        36.204483  -3.299394
                   Feed Rate x Stir Rate x Temperature x Concentration (Level (10, 100, 1
80))       65.459379        62.062297  -3.397082
                                                    Catalyst x Temperature (Leve
l 2)       48.667309        44.876387  -3.790922
                                                Temperature x Concentration (Level
180)       46.371165        42.151102  -4.220063
                       Feed Rate x Catalyst x Temperature x Concentration (Level (10, 2, 1
80))       46.020584        41.581319  -4.439266
                                                     Feed Rate x Catalyst (Level
10)       49.108701        44.037465  -5.071237
                                                                          Feed
Rate       46.573083        40.526837  -6.046246
                         Feed Rate x Catalyst x Stir Rate x Concentration (Level (15, 1, 1
00))       37.628922        31.580940  -6.047982
                                       Feed Rate x Catalyst x Stir Rate (Level (15,
1))       34.604931        28.489952  -6.114979
                                                   Feed Rate x Concentration (Level
10)       49.890462        43.255704  -6.634757
Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (10, 1, 100, 1
40))       37.454012        30.424224  -7.029788
```

```
                                        Feed Rate x Catalyst x Temperature (Level (15,
2))       53.060640        45.951823  -7.108817
                                                                                Concentra
tion       47.511706        39.588214  -7.923492
                                Catalyst x Stir Rate x Concentration (Level (1, 1
00))       43.205839        34.798276  -8.407563
                              Stir Rate x Temperature x Concentration (Level (100, 1
80))       57.492048        48.878854  -8.613194
                                Feed Rate x Stir Rate x Temperature (Level (15, 1
00))       51.345665        42.610064  -8.735600
                     Catalyst x Stir Rate x Temperature x Concentration (Level (2, 120, 1
80))       19.787181        10.848727  -8.938454
                        Feed Rate x Catalyst x Stir Rate x Concentration (Level (10, 2, 1
20))       18.416682         9.297214  -9.119468
                                             Feed Rate x Concentration (Level
15)       45.132950        35.920723  -9.212227
                                               Feed Rate x Temperature (Level
15)       45.457410        35.596263  -9.861148
                         Feed Rate x Catalyst x Stir Rate x Concentration (Level (10, 1, 1
00))       48.782757        38.015611 -10.767145
                                Feed Rate x Stir Rate x Temperature (Level (15, 1
20))       39.569156        28.582461 -10.986695
                                           Temperature x Concentration (Level
140)       48.652247        37.025326 -11.626921
                              Feed Rate x Temperature x Concentration (Level (10, 1
80))       58.849234        47.002773 -11.846460
                                        Feed Rate x Catalyst x Temperature (Level (15,
1))       37.854181        25.240702 -12.613478
                                                Feed Rate x Stir Rate (Level
15)       46.977864        34.075809 -12.902056
                                 Feed Rate x Catalyst x Concentration (Level (10,
2))       50.678013        37.396917 -13.281096
                    Feed Rate x Stir Rate x Temperature x Concentration (Level (15, 120, 1
40))       46.212988        32.925325 -13.287663
                    Feed Rate x Stir Rate x Temperature x Concentration (Level (15, 100, 1
80))       49.524717        35.695411 -13.829306
                              Catalyst x Temperature x Concentration (Level (2, 1
80))       51.843151        37.909623 -13.933528
                              Feed Rate x Stir Rate x Concentration (Level (10, 1
00))       65.861050        51.756116 -14.104935
                                  Catalyst x Stir Rate x Temperature (Level (1, 1
00))       46.068033        31.936082 -14.131951
Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (10, 1, 100, 1
80))       60.111501        45.606998 -14.504503
Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (10, 2, 120, 1
80))       21.233911         4.645041 -16.588870
                                Catalyst x Stir Rate x Concentration (Level (2, 1
20))       35.447857        18.070756 -17.377101
                        Feed Rate x Catalyst x Stir Rate x Concentration (Level (10, 2, 1
00))       82.939344        65.496620 -17.442725
                                             Stir Rate x Concentration (Level
100)       61.944860        43.841587 -18.103272
                     Catalyst x Stir Rate x Temperature x Concentration (Level (1, 100, 1
40))       55.326703        36.809363 -18.517340
                                                                              Stir
Rate       52.893224        34.206696 -18.686528
```

```
                Catalyst x Stir Rate x Temperature x Concentration (Level (2, 100, 1
80))       83.899121        64.970520 -18.928602
                 Feed Rate x Catalyst x Temperature x Concentration (Level (10, 1, 1
80))       71.677883        52.424228 -19.253655
                                     Feed Rate x Catalyst x Stir Rate (Level (15,
2))       59.350798        39.661666 -19.689132
                Feed Rate x Stir Rate x Temperature x Concentration (Level (10, 120, 1
80))       52.239088        31.943249 -20.295838
                              Feed Rate x Temperature x Concentration (Level (15, 1
40))       56.372805        34.542016 -21.830788
                                Feed Rate x Stir Rate x Concentration (Level (15, 1
00))       58.028669        35.927059 -22.101610
                 Feed Rate x Catalyst x Temperature x Concentration (Level (10, 2, 1
40))       55.335441        33.212515 -22.122927
                                                    Catalyst x Concentration (Leve
l 2)       58.065869        35.477828 -22.588041
                                   Catalyst x Stir Rate x Temperature (Level (2, 1
20))       38.200659        15.317954 -22.882705
                 Feed Rate x Catalyst x Temperature x Concentration (Level (15, 2, 1
80))       57.665718        34.237928 -23.427790
Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (10, 1, 120, 1
80))       83.244264        59.241457 -24.002807
                                                      Feed Rate x Stir Rate (Level
10)       58.808583        34.337583 -24.471000
                Feed Rate x Stir Rate x Temperature x Concentration (Level (10, 100, 1
40))       66.262721        41.449934 -24.812788
                   Feed Rate x Catalyst x Stir Rate x Concentration (Level (15, 2, 1
20))       52.479033        26.844298 -25.634734
                Catalyst x Stir Rate x Temperature x Concentration (Level (2, 120, 1
40))       51.108533        25.292785 -25.815748
                              Stir Rate x Temperature x Concentration (Level (100, 1
40))       66.397671        38.804321 -27.593350
                                     Catalyst x Stir Rate x Concentration (Level (2, 1
00))       80.683881        52.884899 -27.798981
Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (15, 1, 100, 1
40))       73.199394        43.194502 -30.004892
                Feed Rate x Stir Rate x Temperature x Concentration (Level (15, 100, 1
40))       66.532621        36.158708 -30.373913
Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (15, 2, 100, 1
40))       59.865848        29.122914 -30.742934
                                   Catalyst x Temperature x Concentration (Level (2, 1
40))       64.288586        33.046032 -31.242555
                                      Feed Rate x Catalyst x Concentration (Level (15,
2))       65.453725        33.558739 -31.894986
                Catalyst x Stir Rate x Temperature x Concentration (Level (2, 100, 1
40))       77.468640        40.799279 -36.669361
                   Feed Rate x Catalyst x Stir Rate x Concentration (Level (15, 2, 1
00))       78.428417        40.273179 -38.155238
                                                        Catalyst x Stir Rate (Leve
l 2)       66.784390        26.759307 -40.025083
                 Feed Rate x Catalyst x Temperature x Concentration (Level (15, 2, 1
40))       73.241731        32.879549 -40.362182
Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (10, 2, 100, 1
40))       95.071431        52.475643 -42.595787
                     Feed Rate x Catalyst x Stir Rate x Temperature (Level (15, 2, 1
20))       61.626899        17.696432 -43.930468
```

```
Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (15, 2, 100, 1
80))       96.990985        51.423444 -45.567541
                   Feed Rate x Catalyst x Stir Rate x Temperature (Level (15, 1, 1
00))       58.196948        11.012914 -47.184034
Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (15, 2, 120, 1
40))       86.617615        36.636184 -49.981430
                                      Feed Rate x Catalyst x Stir Rate (Level (10,
2))       74.217982        13.856948 -60.361034
```

Conclusion

With our randomly generated responses (percent reacted) and with our random seed (42), we find that increasing the Catalyst level is the most impactful, single factor that can improve percent reacted with a 6% contribution. An overall grading of factors is as follows in the following form (Factor, Percented Reacted Change)

1. Catalyst (+6%)
2. Temperature (+1.4%)
3. Feed Rate (-6%)
4. Concentration (-7.9%)
5. Stir Rate (-18.7%)

Notice that increasing the level of Feed Rate, Concentration, and Stir Rate negatively impacts percent reacted if we are examining these factors indvidually. However, the individual examinination in itself doesn't fully capture coupled impacts, therefore investigating combonations of factors percented reacted change is more valuable. I generated 121 combonations of different factors and ultimately found some combonations of the 5 factors yield the best mean change in percent reacted. For example the top 2 combonations include:

1. Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (10, 1, 120, 140)) which has a Percent Reacted Change of +45.6%
2. Feed Rate x Catalyst x Stir Rate x Temperature x Concentration (Level (15, 1, 120, 180)) which has a Percented Reacted Change of +42.6%

In esssence, if we have those factors with their accompanying factors and then increase the concentration, this will dramatically and postiviely impact our overall chemcial reaction percent reacted. Following these combos of 5 factors, the next most impactful combos are 4 factors that follow a similar trend. Commenting on some pair combonations, the top two paired combonations positively impacting percent reacted are:

1. Feed Rate x Catalyst (Level 15) which has a Percent Reacted Change of +18%
2. Feed Rate x Temperature (Level 10) which has a Percent Reacted Change of +12.7%
3. Catalyst x Concentration (Level 1) which has a Percent Reacted Change of +6.7%

As evidenced, each of these factors has unique, coupled impacts when combined and it's important to understand the nuance associated with each of these. If I was an engineer on this experiment, I would keep in the back of my mind the overall net increase that increasing

the catalyst level can bring, however, I would specifically pay attention to the coupled impacts with multiple factors and atttempt to understand the underlying phyiscal reasoning to better increase the overall net, percent reacted for my chemical reactions.