
 **How to Plan and Analyze a Verification DOE**

Before we get started, feel free to download the presentation from our website (no data files with this one.)


<http://www.statease.com/webinar.html>

Assumed knowledge:  
Fractional factorial designs and aliasing


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 **Who We Are**  
This Month's Webinar


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**Learning Objectives**

How to Plan and Analyze a Verification DOE

At the conclusion of this session you should be able to:

- Select an appropriate factorial design for a verification DOE.
  - Aliasing (appropriate resolution)
  - Power (appropriate size)
- Interpret the results from a verification design.

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**Transition**

How to Plan and Analyze a Verification DOE

Our talk has three parts:

- 1. Broad brush description of a factorial design planning process**
2. Illustrate key points via an example
3. Summary

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## Factorial Design Planning Process (1 of 2)

1. Identify opportunity and define objective.
2. State objective in terms of measurable responses.
  - a. Define the change ( $\Delta y$ ) that is important to detect for each response.
  - b. Estimate experimental error ( $\sigma$ ) for each response.
  - c. Use the signal to noise ratio ( $\Delta y/\sigma$ ) to estimate power.
3. Select the input factors to study. (*Remember that the factor levels chosen determine the size of  $\Delta y$ .*)

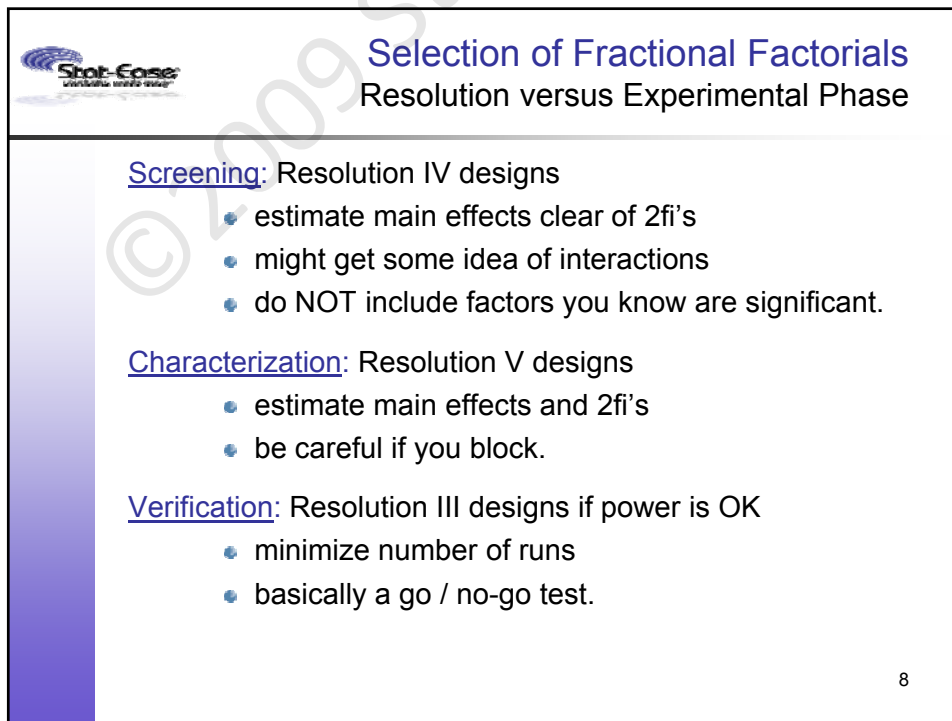
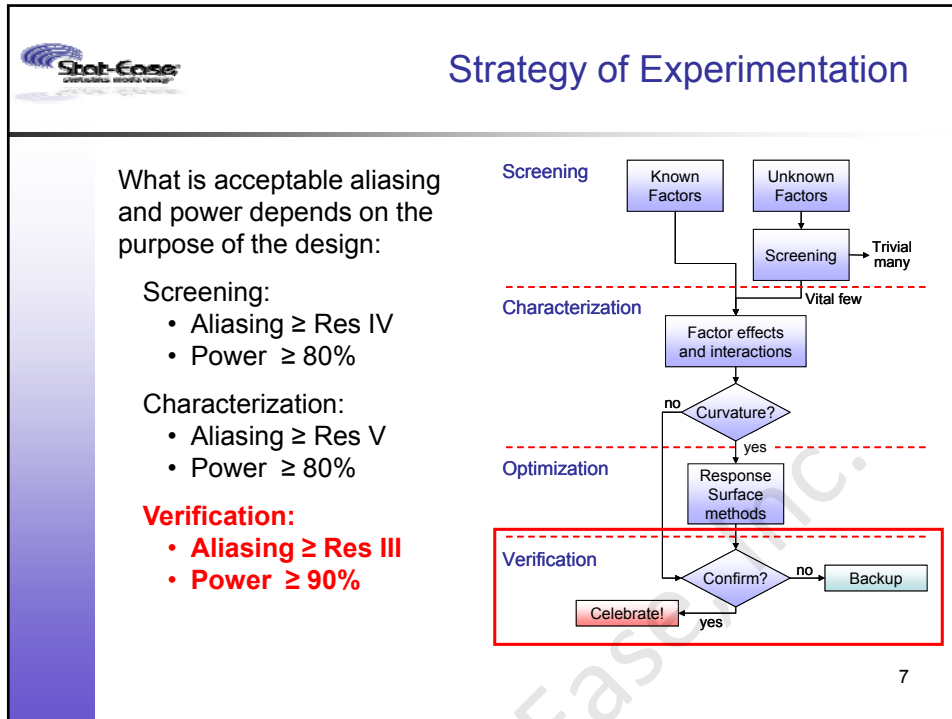
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## Factorial Design Planning Process (2 of 2)

4. Select a design and:
  - Evaluate aliases (fractional factorials and/or blocked designs).
  - Evaluate power (probability of finding an effect of a given size, i.e.  $\Delta y/\sigma$ ).
  - Examine the design layout to ensure all the factor combinations are safe to run and are likely to result in meaningful information (no disasters).

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## Validation versus Verification


Validation: The requirements for a specific intended use are consistently fulfilled.

- Satisfying external (customer) needs.
- Implies the voice of the customer has been successfully translated into specifications.
- Ensuring “you built the right product.”

Verification: Compliance to internal requirements.

- Implies meeting specifications.
- Ensuring “you built the product right.”

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## Verification Testing

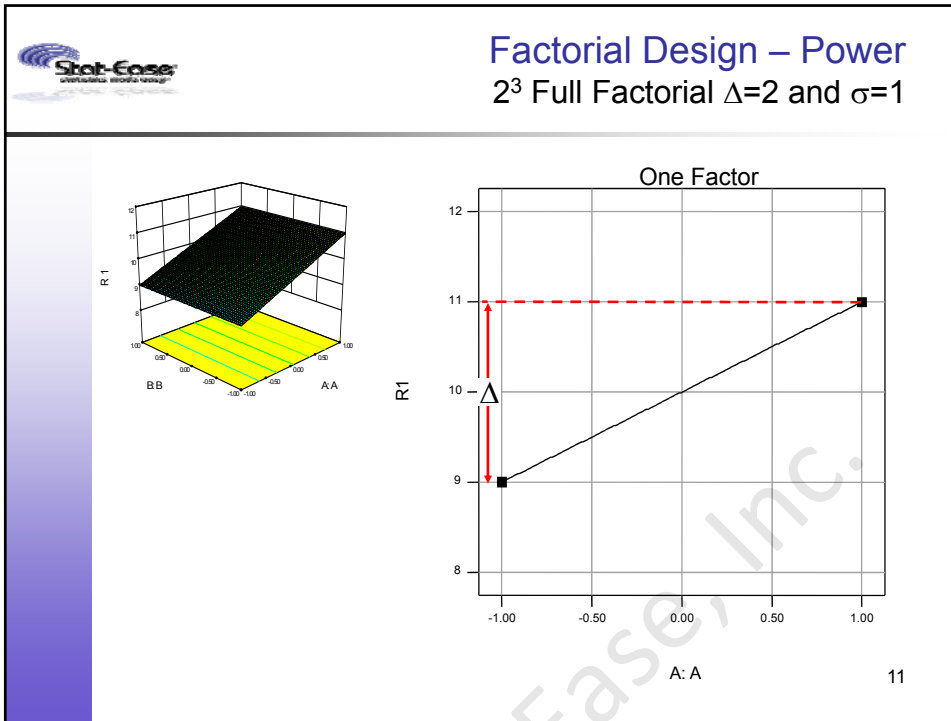
Strategy: Vary key factors over ranges that are expected to be encountered during normal use.

- Process or product should be "robust" to these normal variations.
- Resolution III design minimizes runs – check power!
- If ANOVA significant, cause unclear, but you will know that additional work is required.

*This application of DOE boils down to a go / no-go test.*

*For verification we hope none of the factor effects are large!*

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**What is Power?**  
 No Factor Effect;  $H_0: \Delta = 0$

Confidence =  $(1-\alpha)*100\%$   
**Power =  $(1-\beta)*100\%$**   
*Desire power to be high (at least 90% for verification) for an effect size of interest,  $\Delta$ .*

ANOVA says...

		Retain $H_0$	Reject $H_0$
Truth is...	No Effect	OK	Type I error (alpha rate) <i>False alarm</i>
	Effect	Type II error (beta rate) <i>Failure to detect</i>	OK

 **Factorial Design – Power**  
2<sup>3</sup> Full Factorial  $\Delta=2$  and  $\sigma=1$

Leave Sigma and Delta fields blank to skip power calculation.

Responses:  (1 to 999)


Name	Units	Diff. to detect Delta("Signal")	Est. Std. Dev. Sigma("Noise")	Delta/Sigma (Signal/Noise Ratio)
R1		2	1	2

Power is reported at a 5.0% alpha level to detect the specified signal/noise ratio.

**Signal (delta) = 2.00    Noise (sigma) = 1.00    Signal/Noise (delta/sigma) = 2.00**  
**A**  
**65.7 %**

Since power is low, we may choose to replicate if the desired detectable effect and the standard deviation are fixed.

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 **Factorial Design – Power**  
**Two Replicates** of 2<sup>3</sup> Full Factorial  $\Delta=2$  and  $\sigma=1$

Leave Sigma and Delta fields blank to skip power calculation.


Responses:  (1 to 999)

Name	Units	Diff. to detect Delta("Signal")	Est. Std. Dev. Sigma("Noise")	Delta/Sigma (Signal/Noise Ratio)
R1		2	1	2

Power is reported at a 5.0% alpha level to detect the specified signal/noise ratio.

**Signal (delta) = 2.00    Noise (sigma) = 1.00    Signal/Noise (delta/sigma) = 2.00**  
**A**  
**96.0 %**

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**Power**

The probability of finding an effect!

Power depends on:

- The size of the difference  $\Delta$ :  
the larger the difference the higher the power.
- The size of the experimental error  $\sigma$ :  
the smaller  $\sigma$  the higher the power.
- The  $\alpha$  risk chosen:  
the larger  $\alpha$  the higher the power.
- Choosing a design appropriate to the problem:  
more orthogonal and larger designs have more power.
- The number of replicates:  
the more runs the higher the power.

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**Transition**


How to Plan and Analyze a Verification DOE

Our talk has three parts:

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- 2. Illustrate key points via an example**
3. Summary

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## Viscosity Verification Test

Conduct a verification test on a laboratory assay for measuring viscosity.

There are 7 key factors and the factor ranges represent normal laboratory variation:

	NAME	UNITS	LOW	HIGH
A	Sample Prep		Short	Long
B	Moisture		Volume	Weight
C	Speed	rpm	1100	1300
D	Mixing time	minutes	2	4
E	Rest time	minutes	30	60
F	Spindle		Type 1	Type 2
G	Cover		Absent	Present

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## Viscosity Verification Test

### Factorial Design Planning Process (page 1 of 2)

1. Identify opportunity and define objective.  
Verify that these 7 critical parameters have no effect on the response when varied in these ranges.
2. State objective in terms of measurable responses.  
Response = Viscosity in mPa-sec.
  - a. Define the change ( $\Delta y$ ) that is important to detect for each response.  $\Delta = 35$  mPa-sec
  - b. Estimate experimental error ( $\sigma$ ) for each response.  
 $\sigma = 20$  mPa-sec
  - a. Use the signal to noise ratio ( $\Delta/\sigma = 1.75$ ) to estimate power.

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## Viscosity Verification Test

### Factorial Design Planning Process (page 2 of 2)

3. Select the input factors to study. (*Remember that the factor levels chosen determine the size of  $\Delta$ .*) *done*
4. Select a design and:
  - Evaluate aliases (fractional factorials and/or blocked designs)
  - Evaluate power (for verification desire power  $\geq 90\%$  an effect of interest) *1 main effect*
  - Examine the design layout to ensure all the factor combinations are safe to run and are likely to result in meaningful information (no disasters)

Try a  $2^{7-4}$  factorial

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## Viscosity Verification Test


### Check Aliasing of $2^{7-4}$

Is the aliasing in the  $2^{7-4}$  (8-run) design acceptable?

[Est. Terms]	Aliased Terms
[Intercept]	Intercept + ABD + ACE + AFG + BCF + BEG + CDG + DEF
[A]	A + BD + CE + FG + BCG + BEF + CDF + DEG
[B]	B + AD + CF + EG + ACG + AEF + CDE + DFG
[C]	C + AE + BF + DG + ABG + ADF + BDE + EFG
[D]	D + AB + CG + EF + ACF + AEG + BCE + BFG
[E]	E + AC + BG + DF + ABF + ADG + BCD + CFG
[F]	F + AG + BC + DE + ABE + ACD + BDG + CEG
[G]	G + AF + BE + CD + ABC + ADE + BDF + CEF

*Resolution III is acceptable in a verification test, as long as the product/process passes the verification test.*

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## Viscosity Verification Test

### Check Power of $2^{7-4}$

Does the  $2^{7-4}$  (8-run) design have sufficient power?

Power at 5 % alpha level

Signal (delta) = 35.00


Noise (sigma) = 20.00

Signal/Noise (delta/sigma) = 1.75

**Power = 54.6 %**

Not sufficient power! Should we replicate?

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## Viscosity Verification Test

### Inadequate Power


Should a fractional factorial be replicated?

**No** – Generally it makes more sense to use a larger fraction, rather than doing a replicate.

- Replicating will only add power.
- Adding another fraction will
  - add power
  - provide the ability to estimate more terms
  - test more combinations of the factors

Try a  $2^{7-3}$  factorial

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## Viscosity Verification Test

### Check Aliasing of $2^{7-3}$

Aliasing in the  $2^{7-3}$  is better (*res IV*) than in the  $2^{7-4}$  (*res III*)

[A] = A + BCE + BFG + CDG + DEF  
 [B] = B + ACE + AFG + CDF + DEG  
 [C] = C + ABE + ADG + BDF + EFG  
 [D] = D + ACG + AEF + BCF + BEG  
 [E] = E + ABC + ADF + BDG + CFG  
 [F] = F + ABG + ADE + BCD + CEG  
 [G] = G + ABF + ACD + BDE + CEF  
 [AB] = AB + CE + FG  
 [AC] = AC + BE + DG  
 [AD] = AD + CG + EF  
 [AE] = AE + BC + DF  
 [AF] = AF + BG + DE  
 [AG] = AG + BF + CD  
 [BD] = BD + CF + EG

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## Viscosity Verification Test


### Check Power of $2^{7-3}$

Does the  $2^{7-3}$  (16-run) design have sufficient power?

Power at 5 % alpha level  
 Signal (delta) = 35.00  
 Noise (sigma) = 20.00  
 Signal/Noise (delta/sigma) = 1.75  
**Power = 90.6 %**

YES! Let's continue with this design.

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## Viscosity Verification Test

### Four Potential Outcomes

1. No significant effects and acceptable variability; successful verification. ☺
2. No significant effects and unacceptable (large) variability; does not verify. ☹
3. Statistically significant effect that is not practically important; qualified verification. ☺
4. Statistically significant effect that is practically important; does not verify. ☹

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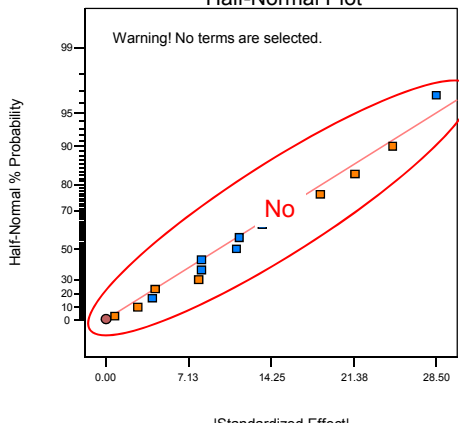
## Viscosity Verification Test

### 1<sup>st</sup> Outcome: Verified

Design-Expert® Software  
Viscosity - Validated

Shapiro-Wilk test  
W-value = 0.963  
p-value = 0.746  
A: Sample prep  
B: Moisture  
C: Speed  
D: Mixing time  
E: Rest time  
F: Spindle  
G: Cover  
■ Positive Effects  
■ Negative Effects

#### Half-Normal Plot

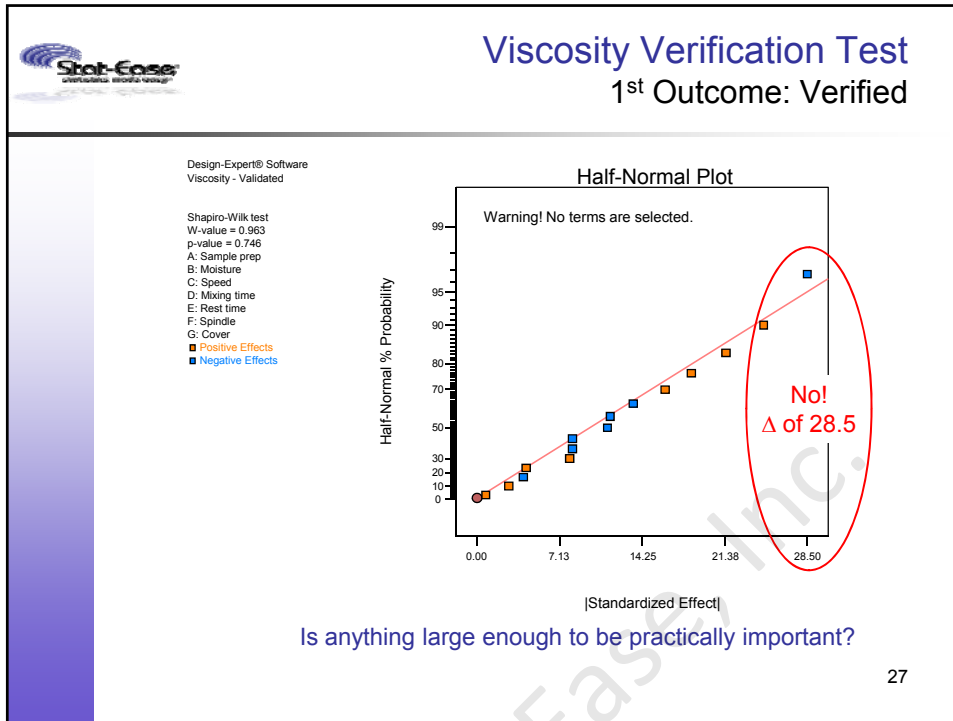


Warning! No terms are selected.

No

Is anything statistically significant?

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### Viscosity Verification Test 1<sup>st</sup> Outcome: Verified

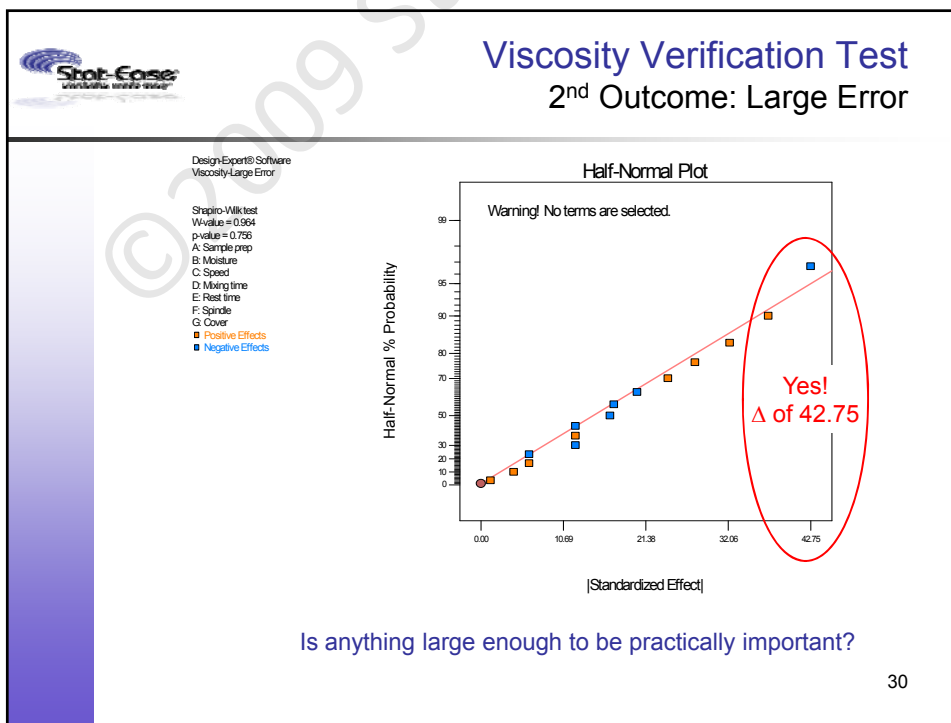
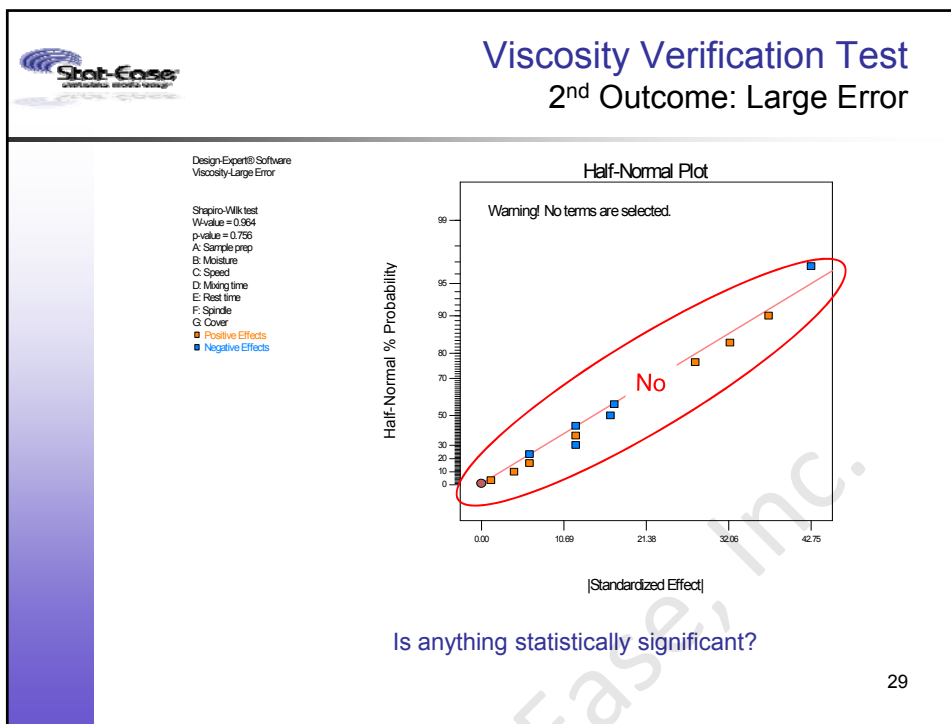
**Conclusion:**


The variation of these 7 factors in their designated ranges did not cause a change in the response that was as large or larger than our specified effect ( $\Delta=35$  mPa-sec)

Success! Verification confirmed.

😊

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## Viscosity Verification Test

### 2<sup>nd</sup> Outcome: Large Error

**Conclusion:**


Although there are no significant effects, the variability in this system is larger than our cut off limit of ( $\Delta=35$  mPa-sec).

The standard deviation was large, but this variability cannot be attributed to any factor effect.

Verification Failure!

☹

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## Viscosity Verification Test

### 3<sup>rd</sup> Outcome: Significant – Not Important

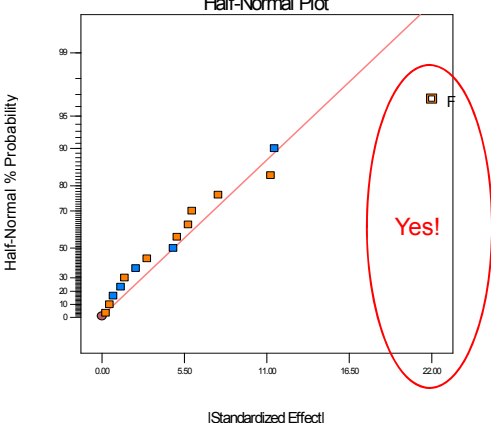
Design-Expert® Software  
Viscosity-Not Practical Effect

Shapiro-Wilk test  
W-value = 0.973  
p-value = 0.918

- A: Sample prep
- B: Moisture
- C: Speed
- D: Mixing time
- E: Rest time
- F: Spindle
- G: Cover

■ Positive Effects  
■ Negative Effects


#### Half-Normal Plot



Is anything statistically significant?

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## Viscosity Verification Test


3<sup>rd</sup> Outcome: Significant – Not Important

**ANOVA for selected factorial model**

**Analysis of variance table [Partial sum of squares - Type III]**

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	1936.00	1	1936.00	14.92	0.0017
<i>F-Spindle</i>	<i>1936.00</i>	<i>1</i>	<i>1936.00</i>	<i>14.92</i>	<i>0.0017</i>
Residual	1817.00	14	129.79		
Cor Total	3753.00	15			

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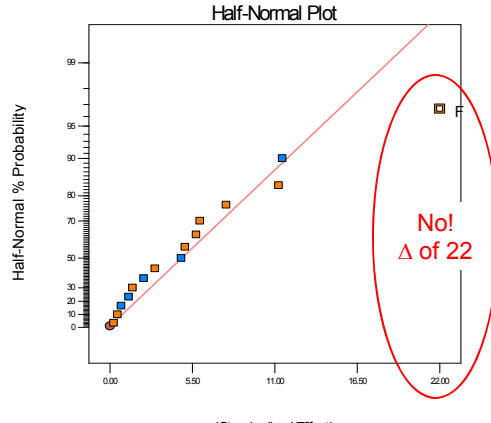


## Viscosity Verification Test

3<sup>rd</sup> Outcome: Significant – Not Important


Design-Expert® Software  
Viscosity-Not Practical Effect

Shapiro-Wilk test  
W-value = 0.973  
p-value = 0.918  
A: Sample prep  
B: Moisture  
C: Speed  
D: Mixing time  
E: Rest time  
F: Spindle  
G: Cover  
■ Positive Effects  
■ Negative Effects



Is anything large enough to be practically important?

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## Viscosity Verification Test

### 3<sup>rd</sup> Outcome: Significant – Not Important


**Conclusion:**

Although varying these 7 factors across their designated ranges did produce a significant effect, the effect detected did not cause a change in the response that was as large as our specified cut off ( $\Delta=35$  mPa-sec)

Success! Qualified Verification

☺

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## Viscosity Verification Test

### 4<sup>th</sup> Outcome: Significant – Important Effect

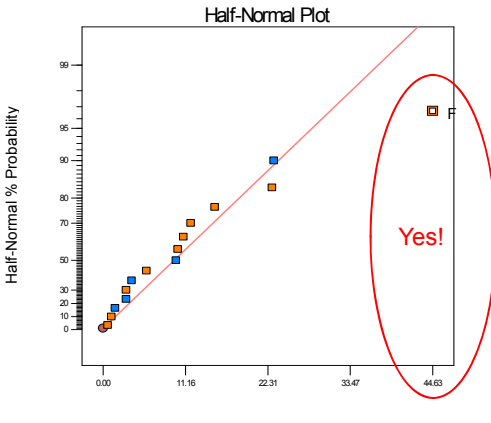
Design-Expert® Software  
Viscosity-Practical Effect

Shepro-Milk test  
W-value = 0.973  
p-value = 0.914

- A: Sample prep
- B: Moisture
- C: Speed
- D: Mixing time
- E: Rest time
- F: Spindle
- G: Cover

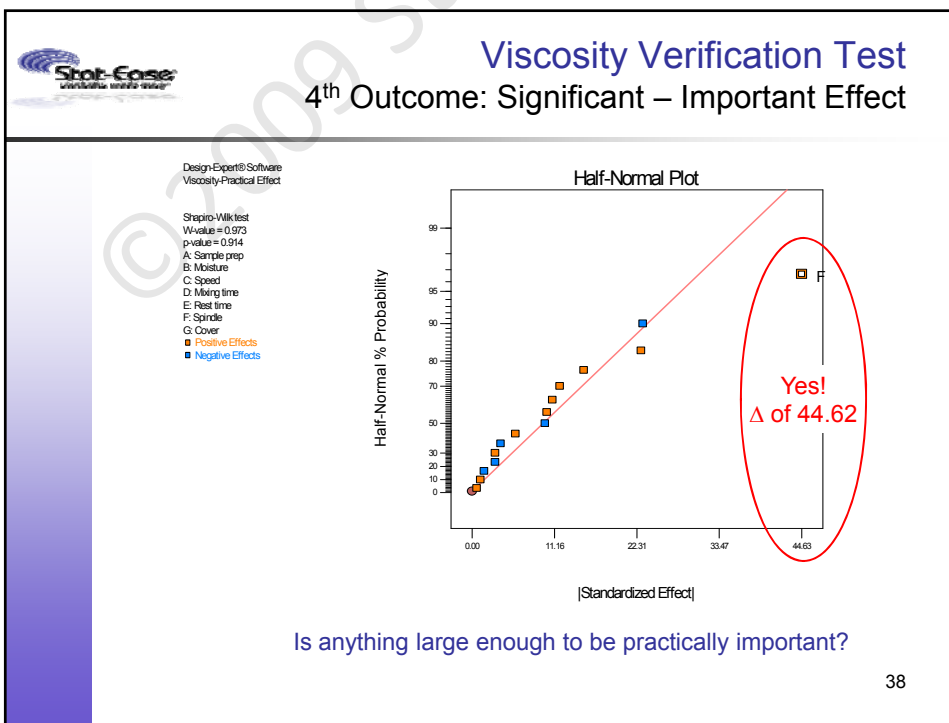
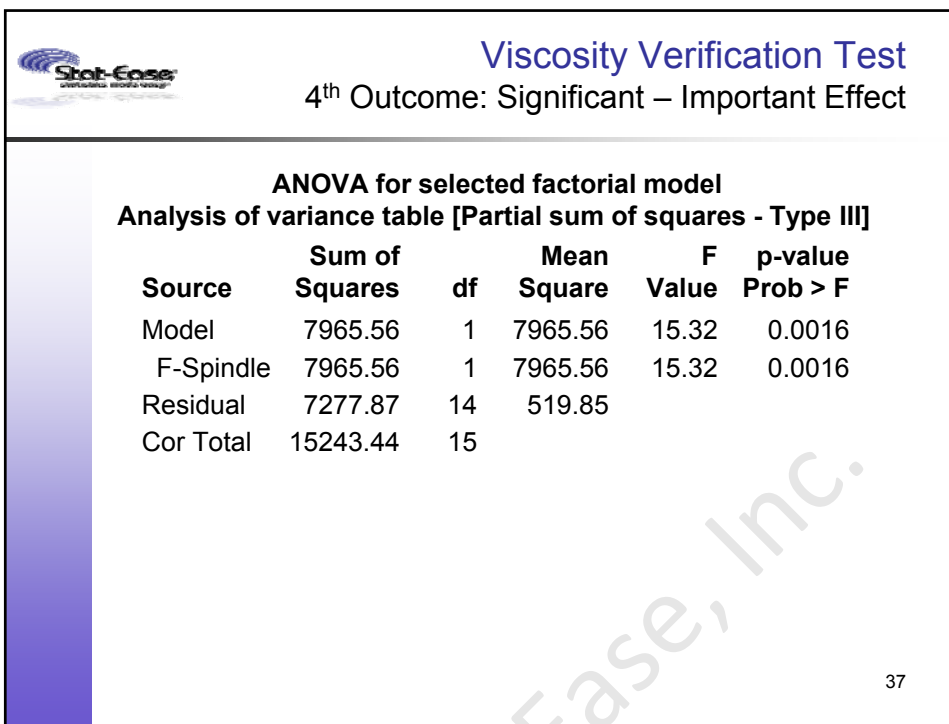
■ Positive Effects  
■ Negative Effects


#### Half-Normal Plot



Is anything statistically significant?

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 **Viscosity Verification Test**  
4<sup>th</sup> Outcome: Significant – Important Effect

Conclusion:  
A statistically significant effect detected that caused a change in the response that was larger (44.62) than our specified cut off ( $\Delta=35$  mPa-sec)

Verification Failure!

☹

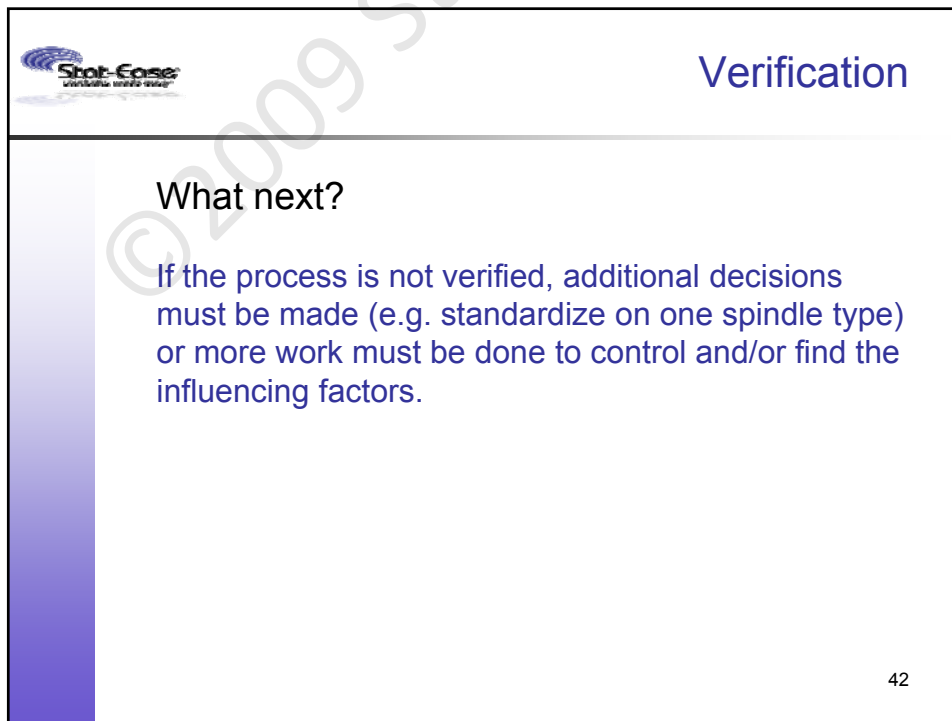
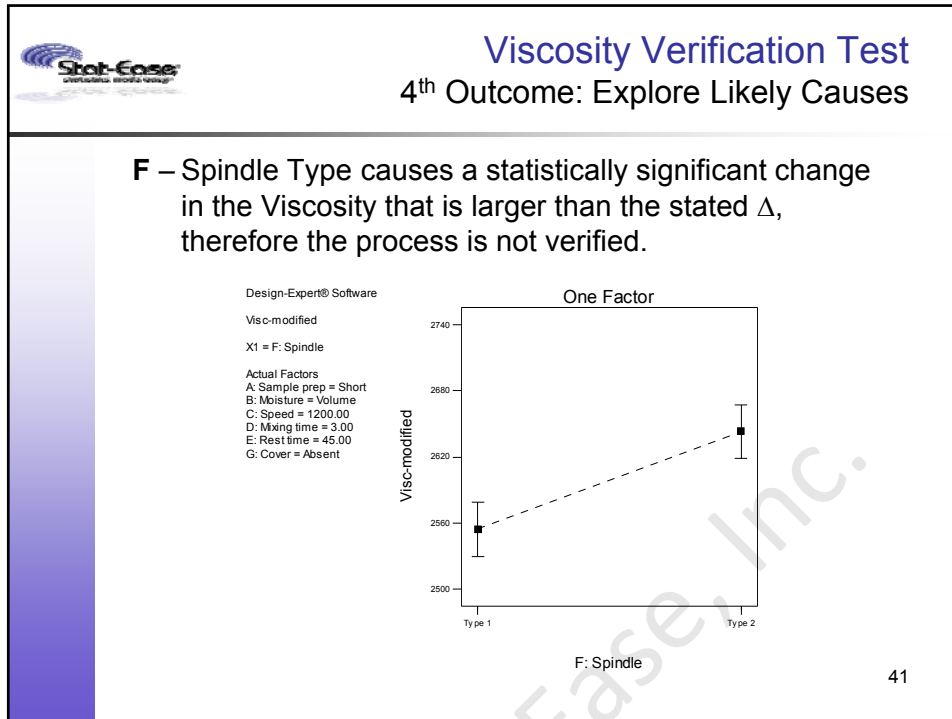
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 **Viscosity Verification Test**  
4<sup>th</sup> Outcome: Check Aliasing

Look at the alias structure:

[A] = A + BCE + BFG + CDG + DEF  
 [B] = B + ACE + AFG + CDF + DEG  
 [C] = C + ABE + ADG + BDF + EFG  
 [D] = D + ACG + AEF + BCF + BEG  
 [E] = E + ABC + ADF + BDG + CFG  
**[F] = F + ABG + ADE + BCD + CEG**  
 [G] = G + ABF + ACD + BDE + CEF  
 [AB] = AB + CE + FG  
 [AC] = AC + BE + DG  
 [AD] = AD + CG + EF  
 [AE] = AE + BC + DF  
 [AF] = AF + BG + DE  
 [AG] = AG + BF + CD  
 [BD] = BD + CF + EG

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Transition

How to Plan and Analyze a Verification DOE

Our talk has three parts:

1. Broad brush description of a factorial design planning process
2. Illustrate key points via an example
3. **Summary**

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Factorial Design Planning Process (1 of 2)

1. Identify opportunity and define objective.
2. State objective in terms of measurable responses.
  - a. Define the change ( $\Delta y$ ) that is important to detect for each response.
  - b. Estimate experimental error ( $\sigma$ ) for each response.
  - c. Use the signal to noise ratio ( $\Delta y/\sigma$ ) to estimate power.
3. Select the input factors to study. (*Remember that the factor levels chosen determine the size of  $\Delta y$ .*)

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## Factorial Design Planning Process (2 of 2)

### 4. Select a design and:

- Evaluate aliases (fractional factorials and/or blocked designs).
- Evaluate power (probability of finding an effect of a given size, i.e.  $\Delta y/\sigma$ ).
- Examine the design layout to ensure all the factor combinations are safe to run and are likely to result in meaningful information (no disasters).

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## Factorial Design Planning Process

What is acceptable aliasing and power depends on the purpose of the design:

### Screening:

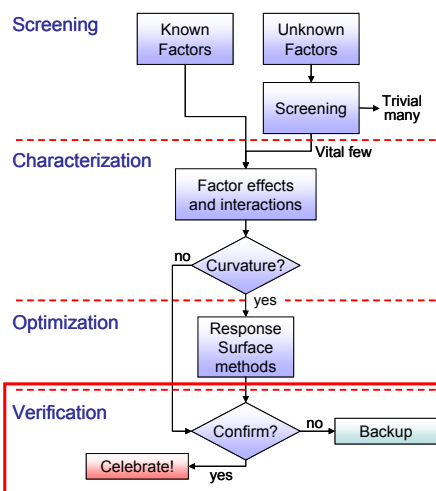
- Aliasing  $\geq$  Res IV
- Power  $\geq$  80%

### Characterization:


- Aliasing  $\geq$  Res V
- Power  $\geq$  80%

### Verification:

- **Aliasing  $\geq$  Res III**
- **Power  $\geq$  90%**



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 **Learning Objectives**  
How to Plan and Analyze a Verification DOE

At the conclusion of this session you should be able to:

- Select an appropriate factorial design for a verification DOE.
  - Aliasing (appropriate resolution)
  - Power (appropriate size)
- Interpret the results from a verification design.

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 **How to get help** 

- Search publications posted at [www.statease.com](http://www.statease.com)
- E-mail [statHelp@statease.com](mailto:statHelp@statease.com) for answers from Stat-Ease's staff of statistical consultants
- Call 612.378.9449 and ask for "statistical help"

***Thanks for attending!***

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