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Case Studies: Correcting Low First-Pass Yield

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Williamette Valley Co. (WVCO, Eugene, OR) produces polyurethane systems used in many industrial applications. In the past, the company had difficulty maintaining high yields when producing these products.

WVCO puts each batch of its polyurethane technology through a demanding battery of tests before shipping it to customers. In the past, WVCO was not satisfied with the production yield. Some batches had to be corrected because of variability in the set time-the amount of time required for the product to solidify after the components are mixed. Another issue was that foaming was seen in some batches. This made it necessary to rework the batch because of its effects on product appearance and performance.

One-Factor-at-a-Time Experiments

WVCO's manufacturing plants are challenged at times with extremes in both temperature and humidity. Plant management had experimented with changing process variables and also had attempted to determine the effect of ambient conditions on responses such as product yield. They had typically varied one factor at a time, such as mixing speed, for a series of batches. The problem with this approach is that it is not able to detect interactions between variables that often have a major impact on key responses. One-factor-at-a-time experimenters often optimize a particular factor only to discover later that after changing other factors, the value that used to be optimal for the first factor no longer provides good results.

The WVCO chemist set out to increase manufacturing yield by designing an experiment that would simultaneously measure the impact of key factors on the critical responses. He hoped to identify not only first order, but also second order and multiple factor effects. The chemist suspected that the ambient conditions at the production plant created a major impact on yield by increasing moisture. The experiments were run at the company's research facility in Oregon where it was not possible to vary humidity levels during the experiments. In order to overcome this problem and simulate a variety of environment conditions, the chemist spiked the resin with moisture based on measurements made at the production plant.

Factor	Name	Units	Type	Low Actual	High Actual
A	Mixing time	Minutes	Numeric	[illegible]	[illegible]
B	Moisture	[illegible]	Numeric	[illegible]	[illegible]
C	Mixing Speed	RPM	Numeric	[illegible]	[illegible]

Table 1: Experimental factors

Table 1.

Design of Two-Level Factorial Experiment

The chemist designed a two-level factorial experiment using Design-Expert statistical-analysis software from Stat-Ease Inc. (Minneapolis). "We selected Design-Expert because it excels at solving real-world industrial problems," says Dr. Phil Cote, WVCO's director of research and development. "Design-Expert has a very intuitive user interface that is geared for engineers, as opposed to statisticians. It provides virtually every experimental design or statistical tool that it would ever make sense to use in an industrial environment. It also saves large amounts of time by automating most of the experimental design and results analysis process." The factors considered in the experiment are shown in Table 1.

Response	Name	Units	Minimum	Maximum
1	Initial Set Time	Seconds	[illegible]	[illegible]
2	Initial Viscosity 10 RPM	cP	[illegible]	[illegible]
3	Initial Viscosity 50 RPM	cP	[illegible]	[illegible]
4	Initial Foam	Score	0	3
5	Set Time 5 Days	Seconds	[illegible]	[illegible]
6	5 Day Foam	Score	0	3

Table 2: Responses measured in the experiment

Table 2.

The software generated an experiment design consisting of 20 runs that targeted the end and center points of each variable. A Morehouse Cowles laboratory mixer equipped with a disk dispenser was used to prepare the resins. The responses shown in Table 2 were measured. A Brookfield DV-II viscometer equipped with a number 5 spindle was used to measure the viscosity of each resin. The set time was checked by hand mixing at a two-to-one ratio using standard laboratory techniques. It was measured as soon as the mixing was completed and again five days after the process was finished in order to evaluate drift during storage.

Response	F-Value	Prob > F	
Initial Set Time	[illegible]	[illegible]	Significant
Initial Viscosity 10RPM	[illegible]	[illegible]	Not significant
Initial Viscosity 50RPM	[illegible]	[illegible]	Not significant
Initial Foam	[illegible]	[illegible]	Significant
5-Day Set Time	[illegible]	[illegible]	Significant
5-Day Foam	[illegible]	[illegible]	Significant

Table 3: Analysis of variance results

Table 3.

Experiment Results Enable Increase in Yield

The chemist entered the results of the experiments back into Design-Expert. The software then provided a variety of statistical analyses. The analysis of variance (ANOVA) results shown in Table 3 demonstrate that the set time and foam were significantly affected by the experiment factors. Note that the significance of these factors increased after the five-day period. This indicates that adventitious moisture is an insidious problem that does not reveal its full impact immediately.

Evaluation of the test factors revealed substantial interactions between the factors. For example, at a low mixing speed, mixing time has little effect on initial set time. However, at a high mixing speed, time has a major effect on initial set. Strong interactions between the mixing speed and mixing time factors also were seen in their effect on foam formation.

After studying the statistical results, the chemist concluded that moisture was the immediate cause of reduced yield. The experiment results also revealed that the effects of moisture could be minimized by reducing the mixing speed and mixing time. The probable cause is that the speeds used in the past generated turbulence that increased the uptake of moisture in the batch.

The experiment showed that the resin could be thoroughly mixed at a lower speed in less time while avoiding the buildup of moisture that had previously hurt yields. The experiment results provided unassailable proof that yields and throughput could be increased by changing processing conditions. When the new optimizing mixing times and speeds were implemented at the production plant, the yields immediately increased. When this change was implemented at the production plant, first-pass yield in the production plant increased by 65% and throughput in the facility increased by 20%.

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Benefits

- Because Design-Experiment software from Stat-Ease can provide a two-level factorial experiment, WVCO gained the advantage in solving a production problem regarding low yield and product defects.

- First-pass yield has been increased from 30% to 85%.

- Throughput has been increased 20%.