Using Six Sigma to Improve PVC Quality

Summary

It was in 1999 when LG Chemical’s PVC production facilities adopted the Six Sigma Initiatives. Although we had never applied Six Sigma methodology in our PVC production lines, it did improve PVC quality. Defining quality from a customer’s viewpoint and applying statistical analysis to identify the factors that influence quality, allowed us to improve chronic quality problems, such as unfused particles on the PVC sheet surface (hereafter Fish-eye). We improved the quality level from 0.72 to 5.3 sigma and above after using Six Sigma tools.

Key Word
Six Sigma, PVC, Polymer, Polymerization, Quality Improvement

Why did we apply Six Sigma methodology?

For many years, we exerted much effort in solving the fish-eye problem. The result of such an endeavor, however, was dismal. Hence, an all-out quality innovation movement involving all concerned parties was initiated. Six Sigma methods were adequate in the following activities:

❖ One Team activities: Experts needed to solve the problem were involved on a full time basis, forming cross-functional teams. This facilitated focusing of resources.
❖ Process improvement: Root causes hidden behind the black box were identified, solving the problem fundamentally. Even after improvements were made, we can continue to maintain steady quality through quality management system.
❖ Customer-oriented activities: All quality indicators were derived from customer’s requirements. By identifying quality issues and level of customers, the complaints and claims were decreased, and customer satisfaction went up.
❖ Quantified data: The level of quality that were vaguely known or difficult to express were quantified. This allowed us to realize the gap between the current quality level versus the target level, and measure results after improvements were made.
❖ Statistical analysis: By statistically analyzing process indicators and conditions that needs to be improved, solutions were easily identified, reducing trial and error, as well as improvement implementation period and the relevant cost.
What did we improve?

While producing PVC into transparent films or sheets using the calender process, the defects of fish-eye like shapes were occurred on the surface caused by unmelted PVC Particles. Such a defect is called Fish-eye. How much of these surface defects are formed within the 100 cm² surface area is an important quality factor.

Through the following improvement initiatives, we were able to achieve 29,000M/T sales for soft transparent sheets, increase 1 million USD worth of profits.

- Through visiting customers and surveys, we identified the quality level that customers required by product groups.
- As the result, the fish-eye like surfacing defect of soft transparent sheets showed the biggest quality gap against that of our competitors.
- By forming cross-functional teams, we focused all our resources into reducing fish-eye on soft transparent sheets.
- By statistically analyzing processing capabilities using Six Sigma tools, priority was set to improve those processes with comparatively low process capabilities.
- After 7 months of improvement efforts, the fish-eye on soft transparent sheets that once had on average, 18 defects per 100 cm² was reduced to 1.

Summary of Improvement Activities

1. Define

As the result of interviewing customers, 59% of the respondents regarded the fish-eye as the most important quality factor in producing soft transparent sheets. This presented as an opportunity to extend our business. The fact that 60% of all our customer’s complaint over the past year derived from the fish-eye problem brought a sense of urgency to improve our situation.
Problem resolution under the Six Sigma initiatives begins with the voice of customers. Despite in-house lab quality approval, if the quality level does not meet customer expectations, we don’t call it a quality product. In order to consistently produce quality products that satisfy customers, we needed to know exactly what the customers wanted and quantify customer requirements.

- **Customer perspectives**
  - Listen to customers to confirm customer requirements (VOC)
  - Define quality issues that customers require
  - Quantify customer quality requirements (CCR)
  - Set internal quality improvement targets (CTQ)

- **Internal perspective**
  - Identify business problems (VOB)
  - Define business issues
  - Quantify requirements needed for the successful business (CBR)
  - Select core improvement processes needed to achieve target quality (CTP)

Customers’ quality requirements that have been derived through such systematic quantifying steps were the key in reducing fish-eye to 2 per 100 cm² when producing soft transparent sheets.

Table 1. Identifying process of CTQ

<table>
<thead>
<tr>
<th>VOB</th>
<th>Biz. Issue</th>
<th>CBR</th>
<th>CTP</th>
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<tbody>
<tr>
<td>- Sales price is lower than competitors</td>
<td>- Quality level up</td>
<td>- Solving root cause</td>
<td>- Surfactant System</td>
</tr>
<tr>
<td>- No good Brand Image</td>
<td>- Improving process capability</td>
<td>- Optimization of process conditions</td>
<td>- Aggregate ppm</td>
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<td>- Injection control mode</td>
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Customer's perspectives

- Fish-eye: max. 2
- Sigma level: min. 4σ

Internal perspectives

- Fish-eye: world class
- Minimize the quality deviation
- Keep the quality consistency
- Too many fish-eyes on the sheet surface
- Quality deviation between lots

VOC: Voice of Customer
CCR: Critical Customer Requirements
CTQ: Critical To Quality
VOB: Voice Of Business
CBR: Critical To Business
CTP: Critical To Process
As such, when customer requirements are quantified, it becomes not only easier to set quality improvement targets but also to analyze post improvement initiative benefits. In order for quantified CTQ to become a more customer-oriented target, it is imperative to find experimental methods that provide the most similar production recipes and conditions of customer processing or customer usage. Also, preciseness and accuracy of these new experimental methods through gage R&R must follow suit. Without such preparatory steps, problems will rise in the course of maintaining quality level of newly developed products.

2. Measure

There are two factors that cause quality deviations.

- **Special Cause**: Signifies quality deviations derived from reasons that are controllable, and as causes are factors that are known, improvements are relatively easy.
- **Common Cause**: Signifies quality deviations derived from reasons not precisely known and improvements are difficult when using general methodologies.

Prior to any new improvement efforts, quality deviations that occur repetitiously through special causes must be resolved. If not, quality deviations will continue even after improving the processes. Successful improvement initiatives, therefore, is unlikely. Repetitive problems that occur by special causes should be solved quickly through quick-win activities.

We gathered the data regarding the fish-eye defect for two months and plotting the observations on C-Chart. We identified two outliers, which immediately became the subject of quick-win initiatives.

![Fish-eye C-Chart](image)

**Cause 1**: In order to maintain consistent quality, the reactive heat occurring during polymerization must be effectively eliminated. To do so, cooling water should be flowing through the exterior jacket of the reactor. However, the cooling water temperature changes in accordance with the outside temperature. The reactive control become inconsistent and
fish-eye increase suddenly. The polymerization recipes were to standardize prescriptions on cooling water temperature to prevent the reoccurrence of the problem.

Cause 2> Once polymerization is completed, residual VCM in PVC was recovered in the Blow-Down tank, and it was recovered again in the stripping tower to decrease residual VCM level under 1 ppm. It was observed that during this process, when the long awaited PVC resin that got accumulated gets mixed up in the Blow-Down Tank as well as in the transfer line to dryer, fish-eye like patterns increased. Through process mapping, we identified where PVC resin can be accumulated and repaired. We prevented the same problem from reoccurring through regular monitoring.

A two-month observation was plotted and as the C-Chart below demonstrates, such quick-win activities allowed reduction of fish-eye like patterns as well as improving deviation. Despite the reduction, however, it was far from satisfactory at 4.5 when customers required two or less. At this point, we began improvement activities to eliminate factors causing quality deviations, i.e. factors that fall under the special cause.

Fig. 4 Fish-eye like pattern trend before & after quick win initiatives

A correlation analysis was conducted to identify which of the unknown conditions of various processes were influencing fish-eye like patterns to occur. In order to effectively gather data needed for correlation analysis, we first defined operational activities. Operational definition means determining what, how and how much measuring is needed. By doing so the basis on how we collect the data is determined. Through operational definition, we gained the following:

- Gives everyone equal weighing of significance.
- Confirms consistency and reliability of data collected
- Clearly illustrates data analysis scope, thereby transferring value meaning into a solid concept.
Using historical process data collected as required by operational definition, we conducted correlation and regression analyses to identify factors causing fish-eye.

- Correlation analysis is a Six Sigma tool that identifies factors among many process indicators that are highly correlated with what we are trying to improve. Figure 5 shows simultaneous comparison of correlation among many process indicators. As the result of the analysis, factor A has a positive correlation with fish-eye like patterns while factor B has a negative correlation.

The correlation analysis identifies variables that have a high probability of influencing fish-eye, but it does not explain how much influence these variables have on fish-eye deviations. Hence, we regressed each of the variables to see how much these variables explain fish-eye deviations. The result is shown in Figure 7.

- Through regression analysis, how influential each of the factors occurrence has been clarified. The movement of factor A explains 62% of fish-eye defect occurrence while factor B explains over 77%.

We decided on factor A and B as CTQ, and initiated aggressive improvement activities.

3. Analyze & Improvement

In order to identify key CTP (Critical to process) that influences CTQ, the following steps
illustrate how we identified influential factors out of many process indicators.

- Clarify the cause & effect relationship of every CTQ through a defining logic tree.
- For the main factors identified through the logic tree, use QFD Matrix to evaluate the degree of importance and influence.
- For factors that have been screened, apply a full factorial design experiment through QFD Matrix, in order to identify CTP, or the vital few.

Figure 8 demonstrates how CTP identified via full factorial designing influences CTQ and how the various factors of CTP interact with one another.

When searching for the optimum conditions of CTP in an effort to achieve the desired level of CTQ, we used response surface analysis. The following are the objectives in conducting response surface analysis.

- Determine the optimum process conditions to satisfy business requirements of processes.
- Select the most efficient improvement measures and identify areas that fit the best.
- Reduce the number of experiments and minimize trial and errors.
Figure 9 below are examples of response surface analyses results.

Using forecasting equations derived through the analysis, we calculated optimum conditions of CTP in achieving CTQ objectives. These estimated CTP conditions, after taking into consideration the scale-up factor, were applied to a commercial plant. As a result, we were able to achieve CTQ goals. Accordingly, factor A and B of CTQ, were able to maintain sigma 4 and above production capabilities.

As factors A and B of CTQ were able to maintain sigma level of 4 and above, fish-eye like patterns
were radically reduced to 1 or below. This C-Chart shows fish-eye trend before any measures were adopted, after implementing quick-win initiatives, and after all measures were applied.

4. Control

Once improvement measures are implemented, what is important is a system establishment for lasting maintenance of consistent quality. For this purpose, we developed the Process Control System.

- Process Control System explains organic relationships among various processes, thereby focusing resources on activities that are most influential on quality.
- Allows goal-setting and ownership endowment for long-lasting successful improvement benefits.
- Facilitates tracking of improvement activity areas, identifying which efforts have had the most influence on improving sigma level. Hence, it can be utilized effectively as a management tool.

Therefore, the Process Control System needs to be regularly revisited, continuously analyzed with real time data, and reported on the results. LG Chemical currently facilitates such real time information through PIS (Process Information System) and QMS (Quality Management System).

Table 2 Process Control System
CONCLUSION

Problem resolution begins with clarifying the customer’s requirements. By using statistical methods, we used root causes and came up with measures for improvement. By implementing Six Sigma initiative, the following shows the benefits that we have attained.

- Experience synergy effects in working with teams cross functionally.
- Minimize trial and error as the result of using Six Sigma tools.
- Learned that boundaryless working and cooperating with other teams allowed on-time achievement of quality targets.
- Applied successful experiment outcome and technology to other product areas with similar quality problems.

REFERENCES