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Experimental Analysis of Heat Transformer Using the Six Sigma Methodology

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Six Sigma Methodology (SSM) for developing new process or product consists of five steps: a) define, b) measure, c) analyze, d) design and e) verify (DMADV). SSM allow developing or improving processes that measure how many defects or failures any process has, in order to find ways to systematically eliminate them. This paper focuses on implementing DMADV to compare the performance of two designs of an experimental heat transformer. We have analyzed the temperature behaviour during the heat transformer operation. The results have been used as information to apply the SSM as follow: a) define; using statistical process control (SPC) to establish whether the temperature is "*in control or out of control*". The objective is found out the opportunity areas. b) measure; we define initially a tolerance error of ±0.5 % over temperature as operation process defect. Then, the process behaviour was monitored in two stages: 1) from the first performance, data was recollected to be analyzed and, 2) another performance was monitored after implemented improvements (the objective is to compare the results). c) analyze; the result was examined in order to calculate the process capability (Cp) and the process capability index (Cp_k). d) design; in this step we have used average control charts, as tools for evaluating the first design to respect the second. Finally, e) verify; the objective of the verify step is found out if the second design of the heat transformer is better than the first one. The results show that the second design of the heat transformer is better than the first design, because it has an enhanced process operation.

1. Introduction

The Six Sigma Methodology (SSM) is a solving-problems technology that involves human resources, variables data and statistical measures to identify and eliminate few vital factors which produce defective products. Therefore, it generates customer's satisfaction and the increasing of company profits consequently (Brue, 2003). Statistically, Six Sigma represents a process behaviour in which the distance between its mean and the nearest specification limit is at least six times standard deviation of the process. The objective is to centre the process on the target and reduce process variation (Markarian, 2004).

The work in this paper focuses on implementing the SSM steps (define, measure, analyze, design and verify, DMADV) to compare the performance of two designs of an experimental heat transformer. The heat transformer is operating in the Applied Thermal Engineering Laboratory, CIICAp – UAEM. We

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have used Six Sigma to create knowledge about the process. In fact, this research is related to design process and to learn about the process performance.

A heat transformer is an absorption heat pump system (Romero and Rodríguez, 2008). It is composed by four main equipments: absorber, generator, condenser and evaporator. Its objective is to increase the heat received at low temperature in to heat at high temperature that can be used as energy in other process (see Figure 1).

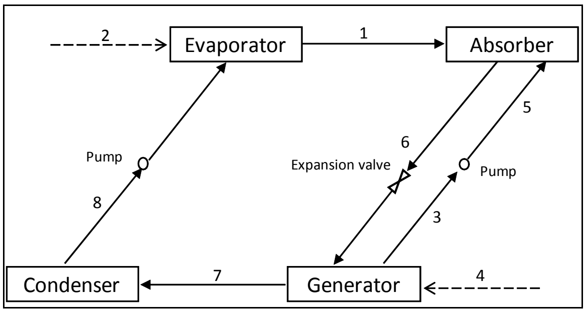


Figure 1: Block diagram of the heat transformer

From the first and second design, data was recollected to be analyzed using statistical process control. The objective was to compare the result. The stream temperature was chose as variable to be monitored.

2. Methodology

2.1 Define

The define step for this project, consisted of selecting all the parameters and necessaries considerations to compare the first design operation behaviour respect to the second one. We defined the customer expectations and specifications.

2.2 Measure

To collect data and monitor the status of the temperature for each stream in two stages, one for the current design of the heat transformer and two when the design changes have been implemented.

2.3 Analyze

The data was examined in order to calculate the process capability (Cp). Using the sigma level proposed by Richard Levin and David S. Rubin (Levin *et al.* 2004) showed in Table 1. We established the Sigma level for each stream. In the case of the process capability index (Cp_k) we made a different analysis. First we calculated the percentage of data out of specifications. Then we compared the results against the percentage showed in Table 1. The objective was to establish if the heat transformer is capability or incapability to reach the client specifications.

Table 1: Sigma level. Minimum values for the process capability index for different ability level and maximum percentage of product out of specifications.

Ability level	Minimum values for the process capability Cp	Maximum percentage of data out of specifications (used to evaluate Cp_k)
± 3σ	1.00	0.26 %
± 4σ	1.33	0.0064 %
± 5σ	1.66	0.00006 %
± 6σ	2.00	0.00001 % (less than)

Calculation formulae:

$$Cp = \frac{USL - LSL}{6\sigma} \quad (1)$$

$$Cp_k = \frac{USL - \mu}{3\sigma} \text{ o } Cp_k = \frac{\mu - LSL}{3\sigma} \quad (2)$$

Where:

USL is the Upper Specification Limit, LSL is the Lower Specification Limit, μ is the mean of the process, σ is the standard data deviation.

2.4 Design

In this step we have used average control charts, as tools for evaluating the first design to respect the second one.

2.5 Verify

The objective of the verify step is found out if the second design of the heat transformer is better than the first one.

3. Results and discussion

3.1 Define

In order to implement the methodology, we have made the following considerations:

a) The temperature was defined as critical variable of the process.
b) We chose only 8 streams (see Figure 1) to be monitored, from 21 that made up the complete system.
c) The monitoring of the data was carried out when the system reached the equilibrium state.
d) The operation parameters defined by the designer are showed in table 2, considering a tolerance of ±0.5 °C.

Table 2: Operation parameters defined by the designer as requirement of the client.

Stream identification	First design Temperature °C	Second design Temperature °C
1 Steam output from evaporator	84.91	83.91
2 Heating water input to evaporator	93.21	92.79
3 Solution output from generator	83.05	81.59
4 Heating water input to generator	93.46	93.07
5 Solution input to absorber	89.75	90.12
6 Solution output from absorber	96.22	95.67
7 Steam input to condenser	83.05	81.59
8 Condensed vapour output from condenser	28.12	31.23

3.2 Measure

For every test, a total of 600 data was recollected for all streams using sensors on-line, with three hours of duration each one. We carried out three tests for the first design and four tests for the second design. The results obtained after data processing are showed in Table 3.

Table 3: Calculation results for each stream.

				First design				
Results	Stream 1	Stream 2	Stream 3	Stream 4	Stream 5	Stream 6	Stream 7	Stream 8
$\bar{x}$	72.13	92.92	81.04	93.19	83.57	83.98	42.77	28.57
$\bar{R}$	1.97	0.11	0.68	0.12	0.76	0.98	0.45	0.08
Σ	0.53	0.03	0.18	0.03	0.20	0.26	0.12	0.02
USL-LSL	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6σ	3.16	0.18	1.09	0.19	1.22	1.57	0.72	0.13
Cp (6σ)	0.32	5.66	0.92	5.19	0.82	0.64	1.40	7.78
Cp (12σ)	0.16	2.83	0.46	2.59	0.41	0.32	0.70	3.89
Cp_k (6σ)	1.00	0.00	1.00	0.00	1.00	1.00	1.00	0.01
				Second design				
Results	Stream 1	Stream 2	Stream 3	Stream 4	Stream 5	Stream 6	Stream 7	Stream 8
$\bar{x}$	85.86	92.32	82.69	92.66	88.16	93.24	50.15	31.31
$\bar{R}$	0.68	0.20	0.21	0.25	0.88	1.25	0.12	0.09
Σ	0.18	0.05	0.06	0.07	0.24	0.33	0.03	0.02
USL-LSL	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6σ	1.09	0.32	0.34	0.40	1.41	2.01	0.19	0.14
Cp (6σ)	0.92	3.11	2.96	2.49	0.71	0.50	5.19	6.92
Cp (12σ)	0.46	1.56	1.48	1.25	0.35	0.25	2.59	3.46
Cp_k (6σ)	1.00	0.29	1.00	0.09	1.00	1.00	1.00	0.00

3.3 Analysis

The objective of this step was to establish whether the process is capable or not to reach the client requirements. Thus, we calculate the percentage of data out of specifications using the areas under the normal curve. As we can observe, for the first design, the calculation results of Cp_k for each stream indicate us that the streams 1, 3, 5, 6 and 7 were incapable to achieve the target of design. In the case of the second design the streams 1, 2, 3, 5, 6, 7 did not meet the client requirements too (see Table 4).

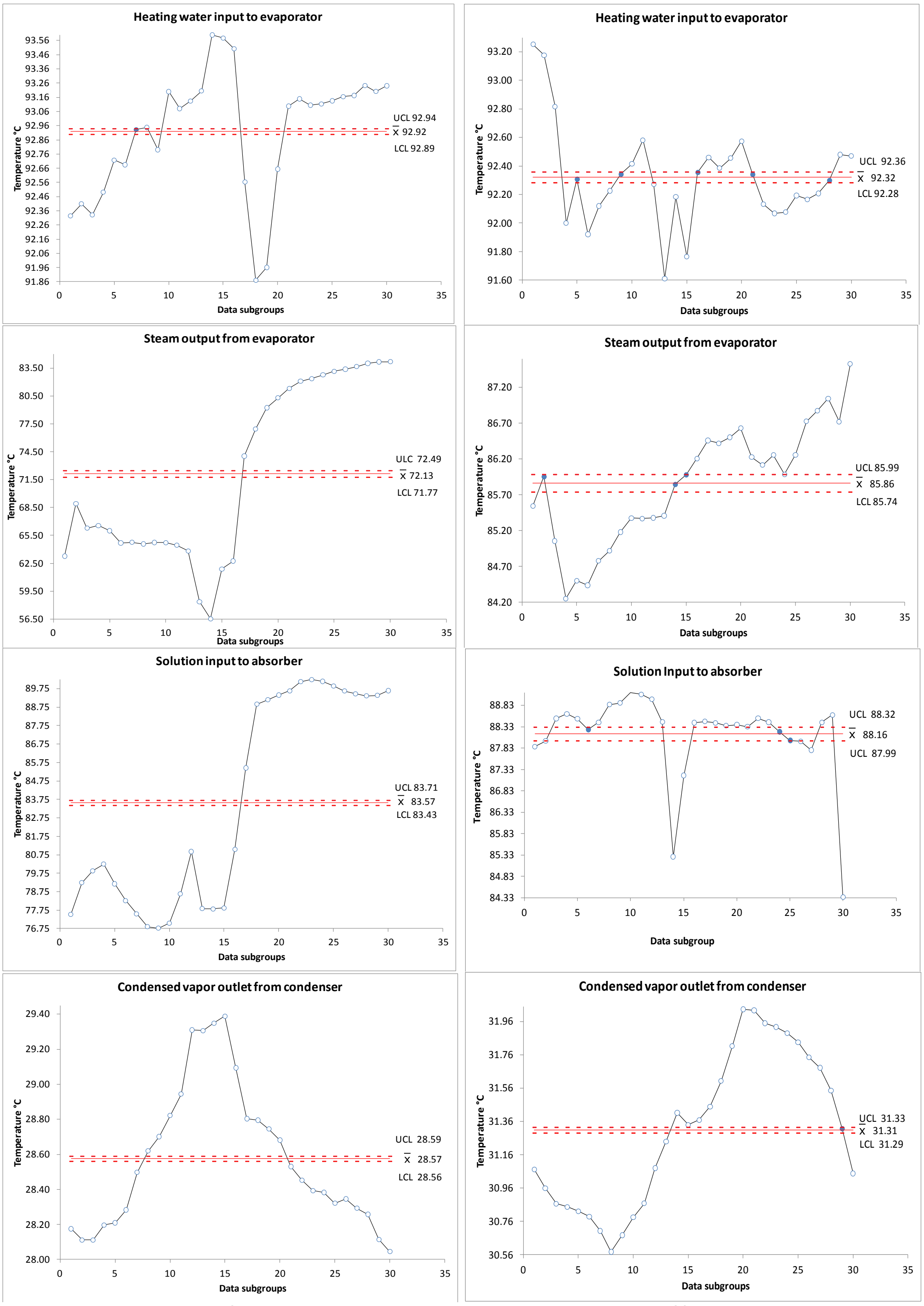
Table 4: Analysis results

				First design				
Results	Stream 1	Stream 2	Stream 3	Stream 4	Stream 5	Stream 6	Stream 7	Stream 8
Cp (6σ)	0.32	5.66	0.92	5.19	0.82	0.64	1.40	7.78
Sigma level	sigma 2	sigma 6	sigma 2	sigma 6	sigma 2	sigma 2	sigma 4	sigma 6
Cp_k (6σ)	1.00	0.00	1.00	0.00	1.00	1.00	1.00	0.01
				Second design				
Results	Stream 1	Stream 2	Stream 3	Stream 4	Stream 5	Stream 6	Stream 7	Stream 8
Cp (6σ)	0.92	3.11	2.96	2.49	0.71	0.50	5.19	6.92
Sigma level	2 sigma	6 sigma	6 sigma	6 sigma	2 sigma	2 sigma	6 sigma	6 sigma
Cp_k (6σ)	1.00	0.29	1.00	0.09	1.00	1.00	1.00	0.00

As we can observe, the sigma level for the second design is better than the firs design, because the level was improve in streams 3 and 7.

3.4 Design

With the data recollected in the measurement step we built control charts for each stream in order to compare the operation behaviour for the two heat transformer designs. The Figure 2 shows the comparison of four streams. As we can observe, the control charts shows a better operation behaviour



a) b)

Figure 1: Heat transformer operation. a) Control charts first design. b) Control charts second design

for the second design as follow:

(a) The data variability in the second design is smaller than the data variability in the first design. For example the data dispersion in the chart called steam output from evaporator is 27°C for the first design whereas in the second design is only 3°C.

(b) There are more points inside of control limits in the second design. For example in the chart of heating water input to the evaporator, for the first design only one point is inside of control limits while for the second design there are five point inside of limits.

(c) Nevertheless, the control charts shows the temperature out of control in the second design, it behaviour is better than the first design, for all the streams.

Subsequently, we assume that the second design is better than the first design, because it has an enhanced process operation.

4. Conclusions

In this work we have implemented the six sigma methodology to compare the performance of two designs of an experimental heat transformer. Using the temperature behaviour during the heat transformer operation we measured the process and the results have been used to calculate the process capability (Cp) and the process capability index (Cp_k). We have used average control charts, as tools for evaluating the first design to respect the second one. Finally, the objective is found out if the second design of the heat transformer is better than the first one. Finally, the application of Six Sigma in chemical process to obtain knowledge is a good way to understand the process behaviour and to found possible alternatives of design.

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