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Treball Final de Màster

Improvement study of the Overall Equipment Efficiency in a resin plant.

Estudio de mejora de la Eficiencia General de los Equipos en una planta de resinas.

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"El cambio es ley de vida, y los que sólo miran al pasado o al presente, seguro que se perderán el futuro."

John Fitzgerald Kennedy

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Report

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1. SUMMARY

The resin plant from AkzoNobel Coatings S.L. detected several delays between the production process and the production planning. For this reason, the Production Manager has started a project to reduce the Overall Equipment Efficiency or O.E.E., which is a percentage that correlates total production hours in a year with all the stops, programmed or not.

In order to analyse the causes of the delays, the different production times have been studied in different level detail:

- The general production times for all the resins in a defined period.
- The reason of the delays for the resins that have reach more rotation in the production planning.
- Application of the last two points in the implementation of the transferred resin from England.

The first part of the thesis studies the reactors responsible for the polyester resins, this study is stopped when the results of the different operations in the process are obtained. The reason for this change is the priority of an important resin from another reactor, the study of the polyester resins serves still as a guide in the new project.

In the implementation of the transferred resin the times are studied and the corrective measures are applied to obtain a considerable time reduction in their process. A process with an average occupation time of 36 hours is reduced to 30 hours and thus, affecting the O.E.E:

R5	Month	August	September	October	November	December	January 2016
	OEE [%]	86%	79%	78%	78%	93%	85%

Table 14. Evolution of the O.E.E. for the reactor 5 from August 2015 until January 2016.

2. INTRODUCTION

AkzoNobel is a Dutch multinational company specialised in decorative paints, performance coatings and specialty chemicals products. The company headquartered in Amsterdam has presence in more than 80 countries with more than 200 productions sites with approximately 47,200 employees.

Figure 1. Logo from AkzoNobel

AkzoNobel was founded in 1994 as a result of the fusion of the company AKZO with Nobel Industries. The company was born after too many acquisitions and mergers, the more notable dates are:

- In 1646 the company Bofors Forge is founded in Sweden.
- In 1969 Algemeene Kunstzijde Unie and Koninklijke Zwanenberg Organon merges to form AKZO.
- In 1984 KemaNobel and Bofors merges to form Nobel Industries.

The last report of AkzoNobel (2014) presented 14.3 € billion of revenue, 987 € million of operating income and 363 € million in RD & Investments. The 9 of February the shares of AkzoNobel costed 53.39 € when the Amsterdam Exchange index was closed (1), (2)

AkzoNobel has a lot of different brands specialty in different products and markets. The next picture shows some of AkzoNobel's brand (3):

Figure 2. A selection of different brands from AkzoNobel

Currently, AkzoNobel has 3 sites in Spain: AkzoNobel Coatings S.L., AkzoNobel Industrial Paints and AkzoNobel Packaging Coatings S.A. The praxis of this thesis takes place in AkzoNobel Coatings S.L. in Barcelona’s site.

In 1965, the company Pinturas Ivanow was founded to make industrial paints and coatings. Afterwards, Pinturas Ivanow was sold to Akzo in 1974. The most relevant acquisition was in 1989 with the company Pinturas Procolor, which had bought the company Industrial Bruguer in 1982. With this acquisition Akzo entered in the decorative painting market.

AkzoNobel Coatings S.L. has 430 employees and produces three kind of products: resins, decorative paints and coatings for cars. Among its brands: Procolor, Bruguer and Sikkens.

Figure 3. AkzoNobel Coatings S.L. from Barcelona’s site, Pinturas Ivanov in 1965 and the actual plant

2.1. AkzoNobel resin plant

One of the most important component of the paints and the coatings is the resin. The resin is the solid product (liquid at the beginning) as a result of the polymerization process of a substance, understanding polymerization as the chemical process where monomers are grouped together making a big molecule called polymer. It could be a lineal chain or a three-dimensional macromolecule.

The site from El Prat has a plant to produce resin in batch for self-consumption and external sales. The resin plant comprises 19 employees: the Production Manager, 3 head of operations, 5 operators and an intern Chemical Engineer. There are three work shifts every 24 hours from Monday until Friday, each shift is basically compounded by a head of operations, 2 operators to control the reactors, an operator to filter the resins and an operator to prepare the raw materials and give support to the rest of the operators of the plant. On the other hand, there are a R&D departments giving support to the resin plant.

As detailed below with a picture of the diagram's plant:

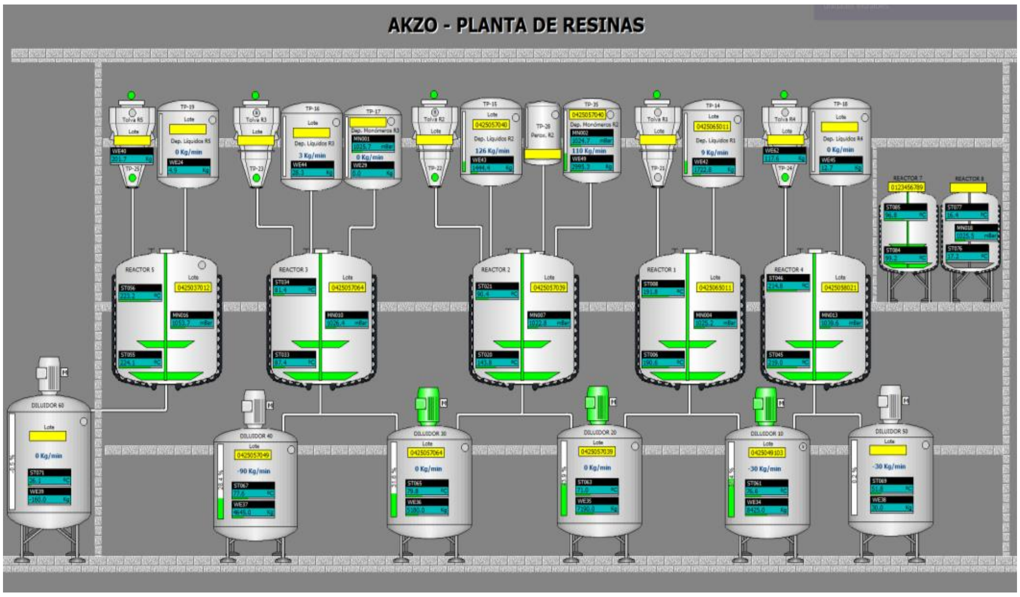


Figure 4. Diagram of the resin plant
(Picture provided by AkzoNobel Coatings S.L.)

Figure 4 shows the main equipment of the resin plant, the plant has:

- 7 reactors. 5 reactors to produce resins (4 of 7 m^3 and 1 of 18 m^3), the pilot reactor (0.12 m^3) and the wax-producing reactor (5 m^3). Each reactor has a column, a condenser and a separator.

- 6 dilution vessel. Each reactor can use 2 different tanks (5 of 13 m^3) except for the Reactor 5, which has its own tank (1 of 40m^3).
- 5 hoppers, 2 tank and 7 deposits. Each reactor has a hopper for the solid raw materials and a deposit for the liquid raw materials. Reactors 2 and 3 have an extra deposit for monomers and tank for peroxides.

The reactors, the dilution tanks and the monomers deposits include a mixer and the plant has 27 buried tanks with different dimensions to storage the liquid raw materials before entering the plant, 3 silos of 50 m^3 to storage the solid raw materials, 4 monomers tanks of 40 m^3 and 16 tanks of finished products.

On top, the plant has the next equipment and services:

- Auxiliary equipment like bombs or forklift.
- Nitrogen service.
- Cleaning service with sodium hydroxide.
- Cooling water service.
- Thermic oil service.

In the resin plant, 3 different class of resin are produced: acrylic resins by polymerization for addition; alkyd and polyester resins by polymerization for condensation. Since there are different kinds of resins for each class (more than 50 different products in total), each reactor has assigned one or two types of resin:

- Reactor 1: Polyester resins.
- Reactor 2: Polyester and Acrylic resins.
- Reactor 3: Acrylic resins.
- Reactor 4: Alkyd resins.
- Reactor 5: Alkyd resins.
- Reactor 7: Pilot reactor.
- Reactor 8: Wax’s reactor

In 2015, 10,226 tonnes of resins were produced in the resin plant.

2.2. Project to improve the Overall Equipment Efficiency

The Overall Equipment Efficiency (O.E.E.) for AkzoNobel is the theoretical production hours in one year deducting all the pauses, inactivity times, plant stops and stops for quality:

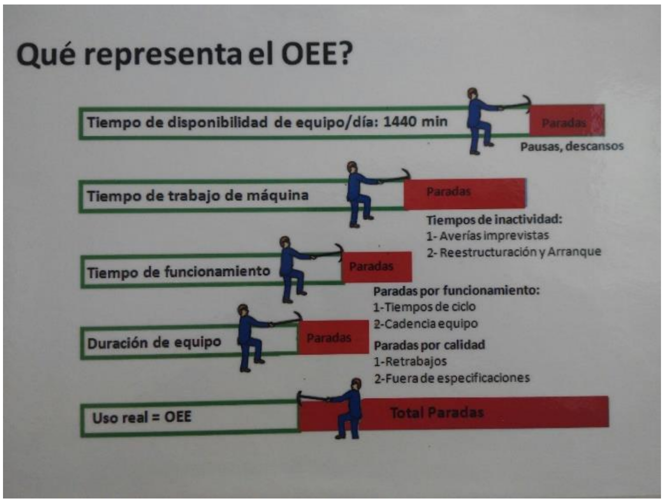


Figure 5. Sketch about the O.E.E. in the resin plant.

The O.E.E. is important because it is involved in the following points:

- High availability of the equipment: reduces the inventory, the delivery schedules and provides to the clients Just In Time.
- High capacity of the equipment: reduces the break downs, stability process and increases the quality of the product.
- High productivity: reduces costs, maximum occupation time for the equipment and gives best economic results.

To evaluate the O.E.E., the head of operations collects the incidents that had result into delays greater than 1.5 hours for acrylic resins, and 3 hours for polyester or alkyd resins, and their logistic incidents. These delays are collected in the incident analysis. The results from January until the end of September are in the next two tables:

Reactor	Productive days / Times collected and O.E.E.	January	February	March	April	May	June	July	August	September	Global
		18	20	22	19	20	20	23	21	19	18
R1	Planning hours [h]	404	476	483	401	352	400	458	203	395	3,571
	Stops [h]	122	204	153	115	57	48	116	11	65	890
	Yield [h]	5	13	6	14	9	20	36	28	30	160
	O.E.E. [%]	68%	55%	67%	68%	81%	83%	67%	81%	76%	71%
R2	Planning hours [h]	424	461	492	441	316	419	476	175	399	3,602
	Stops [h]	144	127	76	119	25	112	86	54	75	816
	Yield [h]	4	13	29	3	6	4	34	2	9	104
	O.E.E. [%]	65%	55%	79%	72%	90%	72%	75%	68%	79%	74%
R3	Planning hours [h]	432	472	499	448	434	457	465	174	417	3,797
	Stops [h]	90	95	54	117	40	74	79	27	55	630
	Yield [h]	15	24	20	16	10	4	12	6	8	112
	O.E.E. [%]	75%	70 %	85%	70%	89%	83%	81%	81%	85%	80%

Table 1. O.E.E. for the reactors 1, 2 and 3 during the studying time.

Reactor	Productive days / Incidents analysis and O.E.E.	January	February	March	April	May	June	July	August	September	Global
		18	20	22	19	20	20	23	21	19	18
R4	Planning work hours [h]	301	374	451	277	255	299	420	166	229	2,769
	Stops [h]	96	69	105	30	36	71	107	25	23	561
	Yield [h]	10	2	36	5	9	17	37	3	20	137
	OEE [%]	65%	75%	69%	87%	83%	71%	66%	83%	81%	75%
R5	Planning work hours [h]	404	369	498	439	478	392	490	173	392	3,634
	Stops [h]	122	60	70	67	51	64	74	13	52	570
	Yield [h]	5	14	14	12	12	9	21	11	33	130
	OEE [%]	46%	80%	83%	82%	87%	82%	81%	86%	79%	78%
Global	Planning work hours [h]	1.904	2.152	2.422	2.006	1.835	1.966	2.308	890	1.831	17,311
	Stops [h]	593	554	457	447	209	367	461	130	269	3,486
	Yield [h]	34	65	105	50	45	53	140	50	99	638
	OEE [%]	65%	81%	77%	75%	86%	79%	74%	80%	81%	77%

Table 2. O.E.E. for the reactors 4, 5 and the global during the studying time.

AkzoNobel considers acceptable an O.E.E. superior than 75 %, the results are accomplished except for reactors 1 and 2. The stops represent the logistic incidents and breakdowns, whereas, the yield are all the delays related to the process. These delays are not investigated, just collected if they are bigger than a specific number.

Hence, the aim of this project is to decrease the number of hours in the stops and yield. In order to do so, it will be held the analysis of the production times. Yield is very general and it does not provide too much information. Also, checking the data base that generates tables 1 and 2, there are detected differences between the information in the data base and the information in the operations sheet from the operators, and the way to collect the information produces confusions when a batch needs to be identified with its incidents. For all of these reasons, the information contained in tables 1 and 2 is just used as an illustrative state of the plant.

This project will start evaluating the general state of the production plant and selecting the most representative resins for each reactor, these resins will be used to represent a global image of the incidents in these respective reactors. The majority of the corrective measures applied in a resin can be extrapolated in other resins from the same family or another reactor if it is a logistical incident.

During the project, for an important reason, the focus was changed. The first part of the project will study the resins from reactors 1 and 2. The second one will study the implementation of a resin transferred from England that presents times not according to what was planned. By evaluating the times of this resin, the weaknesses will be corrected.

All the studies have been done with Excel by Microsoft Office. For confidentiality reasons, it is tried to providing just the necessary information to understand the thesis and to respect the privacy of the company is attempted.

3. OBJECTIVES

The objective of this thesis is to investigate the variability in the production process and to determinate the corrective measures for short-term and mid-term that can solve the deviation. If the production times are reduced, the productivity of the plant, the capacity and the availability of the equipment will increase.

To achieve the objectives, the next steps have been followed:

- Collecting the times of all the batches during the study period.
- Selecting the most representative resins for each reactor.
- Studying in detail the selective resins to find the representative weaknesses of the process.
- Evaluating and applying corrective measures.

The same objective is valid for both parts of the thesis.

4. GENERAL TIME STUDY

The first step is to create a data base to study superficially the production time in order to have a general view about which resins require more time in their production. In this case, the project consists in improving the times during the process in the reactors. Therefore, it is used the occupation time of the reactor. This parameter is the time that the reactor is occupied producing a resin and it can't start another batch.

From January until September (included), the production order, the occupation reactor time and the assigned reactor have been gathered for each batch.

10 resins with the higher total occupation time are selected with the reason to obtain a global and an approximated view of the production process situation for each resin class. The results are:

Reactor	Resin code	Resin class	Total occupation time [h]	Total occupation time [%]
4 and 5	Z3S348	Alkyd	2456	15.56
1 and 2	Z2G130	Polyester	1139	7.22
1 and 2	Z2G086	Polyester	848	5.38
4 and 5	Z9910	Alkyd	847	5.37
4 and 5	Z3A148	Alkyd	787	4.99
1 and 2	Z3Z072	Polyester	723	4.58
2 and 3	Z2A946	Acrylic	645	4.09
2 and 3	Z2A219	Acrylic	616	3.91
1 and 2	Z2P128	Polyester	561	3.56
2 and 3	Z2A579	Acrylic	447	2.83

Table 3. Results of the general study of the time for the different resins

For these resins, it has been calculated their average occupation time and their standard deviation. The average is the division between the occupation time of one resin and the total number of batch produced for its resin, while the standard deviation is for measuring how far or close are the values of the different batches from their average, the standard deviation is dimensional-less. These values provide information about the time to produce a batch and which resins present more consistent occupation times.

All the batches that had a long delay during the process or that had a weekend in the middle of the process are rejected from the data base, with the objective to obtain results according to reality.

Reactor	Resin	Resin class	Average of the occupation time [h]	Standard deviation [-]
4 and 5	Z3A148	Alkyd	29.81	12.14
1 and 2	Z2G130	Polyester	26.34	4.57
4 and 5	Z3S348	Alkyd	19.66	3.27
4 and 5	Z9910	Alkyd	24.34	2.73
1 and 2	Z2G086	Polyester	22.44	2.53
1 and 2	Z3Z072	Polyester	21.28	1.94
1 and 2	Z2P128	Polyester	16.66	1.15
2 and 3	Z2A579	Acrylic	9.64	1.11
2 and 3	Z2A219	Acrylic	9.69	1.07
2 and 3	Z2A946	Acrylic	10.65	0.75

Table 4. Average and standard deviation for the 10 resins which taken more total occupation time.

Table 4 shows in the standard deviation column, that the alkyds and the polyesters resins present more dispersion in their batch times. Therefore, the production process time of these resins present more variability. A more detailed study could identify the causes that provoke the variability in the process time.

As this point, the Project Manager decided to focus the project to study the variability of the reactor 1 and 2.

After analysing reactors 1 and 2 times and the influence of the resins of the table 4, the resins Z2G130 and Z3Z072 are chosen as a reference of the state of the reactors 1 and 2, keeping in mind that the resin process for the resins Z2G130 and Z2G086 are equal.

The objective of analysing these resins is to detect the big causes that are provoking considerable deviations in the occupation time for the same product and consequently reducing the production plant capacity.

The results are:

	R1	R2
Total occupation time [h]	2760	3455
Polyester resins occupation time [h]	2385	2301
% Polyester resins regarding total O.T.	86%	67%
Z2G130 [h]	704	435
% Z2G130 regarding total O.T.	26%	13%
Z3Z072 [h]	294	248
% Z3Z072 regarding total O.T.	11%	7%

Table 5. Analysis of the reactors 1 and 2 for the selected polyesters resins.

To know the variability of reactors 1 and 2, it is studied the production process of the selected resins and the production process is divided in different steps. The objective of the division is to enclose the causes of the variability to identify them better. As the dimensions of reactors 1 and 2 are the same, it is done the hypothesis that the reactor have no influence in the occupation time.

5. POLYESTER RESINS

Polyester resins are polymerized by condensation. They are produced by the reaction of an acid with an alcohol, it produces an ester and water (receives the name of polymerization by condensation because the reaction produces water or an alcohol). This reaction not only produces the desired product, but three sub-products that represent the 50% of the reaction yield (4).

Polyester resins present the following properties:

- Polyester resins are thermostable.
- Polyester resins harden in normal conditions' temperature.
- Polyester resins present resistance to humidity, chemical products and mechanic forces.
- Polyester resins dry faster, tolerating easier the excess of working conditions.
- Isophthalic polyester resins show a high resistance to chemical agents and corrosion.

This class of resin's applications are:

- As the matrix to make equipment, anticorrosive piping and paints.
- To make fibres and coating plates.
- To strengthen surface, polyester resins provide mechanical resistance.

5.1. Z2G130 resin

Theoretically, the resin Z2G130 needs 27 hours to be produced, being the average occupation time of the different batches a little bit more than 26 hours. The results are similar, even the average occupation time of the batches is less than the theoretical occupation time, but this reason does not justify the standard deviation value.

The production process of the resin Z2G130 has 2 parts, the first part is produced in the reactor and the second part is produced in the dilution tank. Each of these parts is divided in the following steps.

Reactor steps:

- First step. Raw materials and reactor conditioning: this operation consists in loading the raw materials from the hopper and the deposits to the reactor, activating the mixing of the reactor and introducing nitrogen gas to prevent the oxidation of the resin.
- Second step. Heating: the set-point of the mass temperature is programed and the process develops until arriving to the reaction temperature. This heating process is done in two steps, one until the boiling temperature of one raw material that is distilled during the reactor steps, the second step is until the mass temperature arrives to the set-point programmed. During this step the water and the solvent are distilled, the water is eliminated and the solvent comes back to the reactor, this operation is called reflux.
- Third step. Reaction: keeping the temperature of the reactor until the acid number of the resin is smaller than a characteristic value.
- Fourth step. Cooling: cooling the reactor first with cold thermic oil until a characteristic safety temperature, under this safety temperature the reactor is cooled by cooling water.
- Fifth step. Unload: unload the resin from the reactor to the dilution vessel.

Dilution vessel step:

- Sixth step. Filtration: filtration of the resin to remove all the defects and collect the resin in a tank, drums or small tanks.

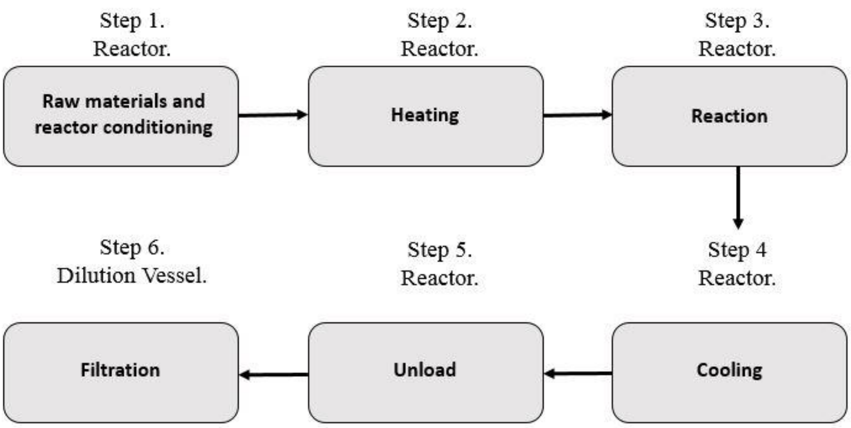


Figure 6. Operation diagram of the resin Z2G130

5.2. Z3Z072 resin

Theoretically, the resin Z3Z072 is produced in 19 hours, the average occupation time of the different batches is not much longer than 21 hours. The average occupation time of the produced batches is 2 hours greater than the theoretical process time. Considering the theoretical process time, 2 hours are accepted in their standard deviation, but the 21 hours are the average including its standard deviation. It is a matter to suspect from a weakness.

The production process of the resin Z3G072 has 2 parts: the first part is produced in the reactor and the second part is produced in the dilution tank. Each of these parts are divided in the following steps.

Reactor steps: The reactors steps are the same than the reactors steps from the resin Z2G130 in the section 5.1, except:

- Fourth step. Cooling and dilution: cooling the reactor first with cold thermic oil until a characteristic safety temperature, under this safety temperature the reactor is cooled by cooling water. When the resin is cold enough, it is dissolved with not much solvent.
- Seventh step. Washed: the reactor is washed with a solvent. After the process, the solvent is unloaded to the dilution tank, where it is mixed with the rest of the resin.

  The washed operation is done after the unload step. The seventh step is held to avoid confusions with the sixth step, filtration.

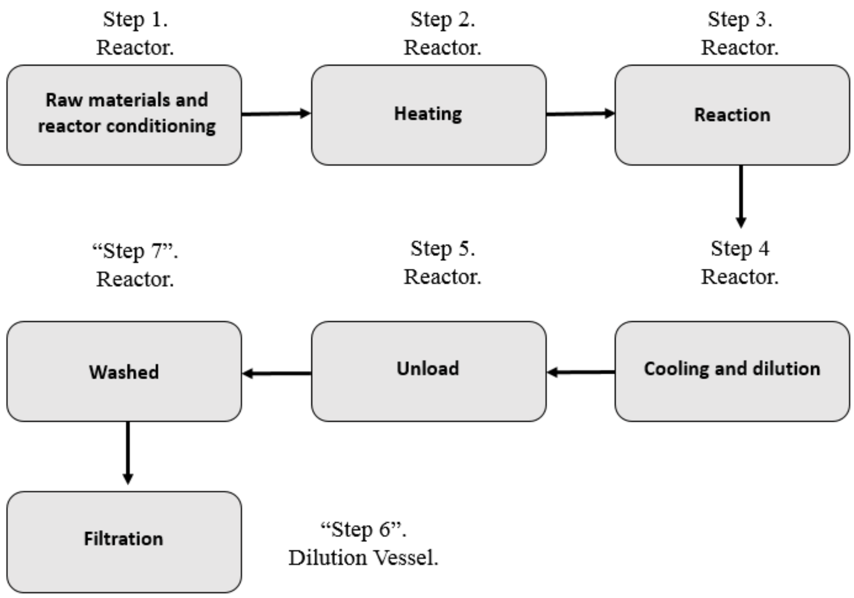


Figure 7. Operation diagram of the resin Z3Z072

5.3. Time study for the polyester resins

With the goal to improve the production capacity of the reactors 1 and 2, the resins Z2G130 and Z3Z072, as a reference resins for this reactor, have been selected. A data base is created to recollect all the different times, keeping in mind the new distribution of the resin's process explained in the section 5.1. and 5.2. In addition, the filtration process is included to calculate the batch time and detect weaknesses in the process.

The data base of the resins Z2G130 and Z3Z072 is doubled to create two data base: one with the real time and the other one with the ideal time. These factors will condition the results obtained and they will be defined in the next paragraph.

In the next study, the following times have been analysed:

- Study of the steps time: steps time is the time of each step of the section 5.1 and 5.2, except the filtration step. The real time rejects the time of the weekend when is in the middle of a batch. In addition, the ideal time rejects too all the plant's incidents reported in the operation pages from the operators.
- Study of the occupation time: occupation time includes all the steps time of the last point. The conditions of the real time and the ideal time are the same that in the last point.

- Study of the dead time: dead time is the time between, the end of the fifth step and the beginning of the sixth step according the section 5.1 and 5.2. The ideal time dismisses the time of the weekend in the middle of a batch. Whereas, the real time includes the discards from ideal times.
- Study of the filtration time: filtration time is the time of the dilution tank step. The ideal time rejects the time of the reported incidents for filter K.O. Real time does not discard times.
- Study of the batch time: batch time includes from the beginning of the production process for a resin until the resin is filtered and ready to leave. The ideal time includes the ideal occupation time, the ideal filtration time and the real dead time. On the other hand, the real time includes the real occupation time, the real filtration time and the real dead time.

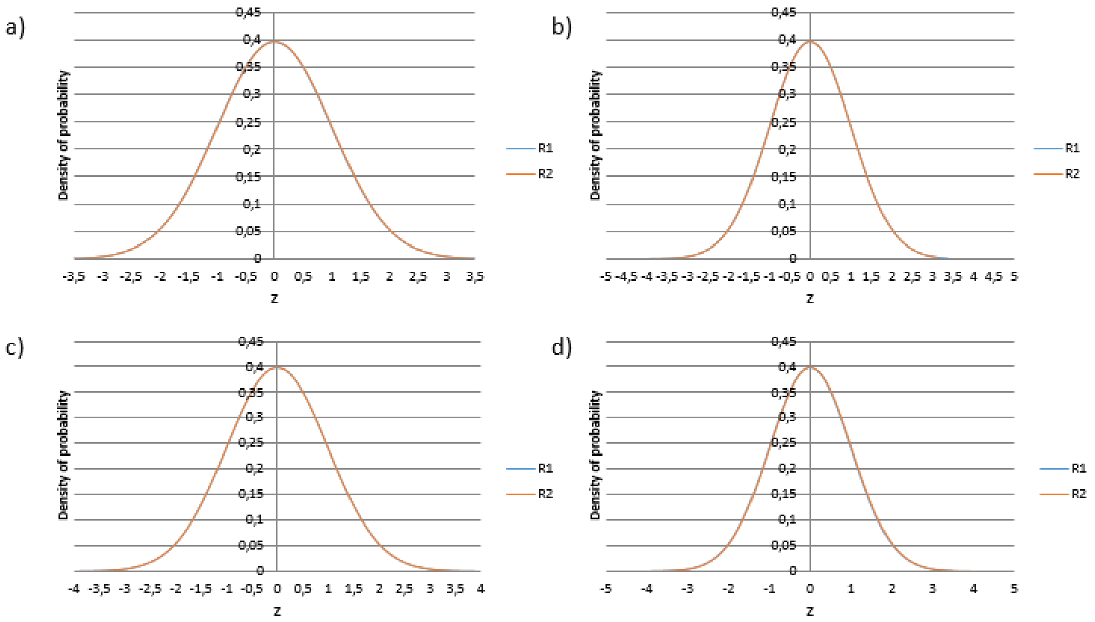
Before extracting results from the study, the hypothesis *"The reactor 1 and the reactor 2 are equal and they have not influence in the process time*" has to be checked. An Analysis Of Variance Test is done to the occupation time to accept or to decline the hypothesis, the **significance level** accepted for the test is 95 % (5).

Resin code	Condition	Reactor	Average [h]	Standard deviation	ANOVA probability	Condition to pass
Z2G130	Ideal	R1	26.36	2.19	0.49	> 0.05
		R2	25.80	2.44		
	Real	R1	31.11	5.37	0.71	> 0.05
		R2	30.31	6.22		
Z3Z072	Ideal	R1	21.27	1.93	0.07	> 0.05
		R2	19.91	1.39		
	Real	R1	27.79	6.27	0.0501*	> 0.05
		R2	22.99	4.60		

Table 6. Results of the Analysis Of Variance Test for the occupation time.
*This result contains 2 decimals more to demonstrate the condition pass.

Checking the results from the table 6, it is accepted that the reactor does not have any influence in the production process time. Except in the real conditions case for the resin Z3Z072, the average and the standard deviation are similar for the different reactors.

To check the results of the table 6, with the same average and standard deviation the standard normal distributions have been represented in the same graph:



a) Resin Z2G130 ideal.
b) Resin Z2G130 real.
c) Resin Z3Z072 ideal.
d) Resin Z3Z072 real.

Blue line: Standard normal distribution for the reactor 1.
Red line: Standard normal distribution for the reactor 2.

Figure 8*. Standard normal distribution for each resin comparing the results in different reactor

*In the figure 8 it can only be seen the line of the reactor 2, because this line is covering up the line of the reactor 1.

Appendix I shows the Box-plot and the Q - Q plot for the reactors 1 and 2.

5.4. Results for the selected resins

In the following pages, the results from the study of the representative polyester resins are showed in the next tables:

Study time	Ideal / Real	N	Average [h]	Standard deviation	Batch with minim value [h]	Batch with maxim value [h]	t (N-1) - Student	Confidence interval of 95% [h]	
								Lower	Upper
Raw materials and reactor conditioning	Ideal	33	1.60	0.58	0.50	2.83	2.04	1.39	1.81
	Real		3.34	3.04	0.67	15.75	2.04	2.24	4.43
Heating	Ideal	33	5.37	1.63	2.92	9.75	2.04	4.78	5.96
	Real		5.65	1.79	2.92	9.75	2.04	5.00	6.29
Reaction	Ideal	33	16.88	2.13	12.08	21.75	2.04	16.11	17.64
	Real		17.91	3.32	12.08	24.92	2.04	16.71	19.10
Cooling	-	33	1.93	0.60	0.75	4.03	2.04	1.71	2.14
Unload	-	27	0.45	0.31	0.25	1.75	2.06	0.33	0.57
Dead time	Ideal	29	12.32	8.83	1.08	39.33	2.05	8.90	15.73
	Real	33	18.56	20.85	1.08	103.83	2.04	11.05	26.07
Filtration	Ideal	28	3.73	1.23	2.25	6.83	2.05	3.24	4.21
	Real	33	4.66	2.97	2.25	16.83	2.04	3.59	5.73
Occupation time	Ideal	33	26.14	2.27	21.58	31.75	2.04	25.32	26.96
	Real	30	30.79	5.63	22.75	46.00	2.05	28.65	32.93
Batch time	Ideal	25	43.33	9.63	29.58	69.42	2.06	39.28	47.39
	Real	26	47.03	9.90	32.25	72.42	2.06	42.95	51.10

Table 7 Results of the study time for the polyester resin Z2G130

Study time	Ideal / Real	N	Average [h]	Standard deviation	Batch with minim value [h]	Batch with maxim value [h]	t $_{(N-1)}$ - Student	Confidence interval of 95% [h]	
								Lower	Upper
Raw materials and reactor conditioning	Ideal	23	3.32	0.62	2.42	4.50	2.07	3.04	3.59
	Real		6.34	4.42	2.67	20.75	2.07	4.38	8.29
Heating	Ideal	23	7.14	1.39	5.08	10.42	2.07	6.52	7.76
	Real		7.49	1.70	5.08	11.33	2.07	6.74	8.24
Reaction	Ideal	23	5.18	1.54	2.67	8.25	2.07	4.50	5.87
	Real		5.32	1.79	2.67	10.25	2.07	4.52	6.11
Cooling and dilution	-	23	2.80	0.59	1.83	3.95	2.07	2.53	3.06
Unload	-	23	0.39	0.10	0.22	0.60	2.07	0.34	0.44
Washed	-	23	1.79	0.59	1.00	3.62	2.07	1.53	2.05
Dead time	Ideal	19	6.84	3.16	1.67	16.00	2.10	5.28	8.41
	Real	23	17.93	25.64	1.67	95.50	2.07	6.59	29.26
Filtration	Ideal	19	4.76	1.95	2.17	8.83	2.10	3.79	5.73
	Real	23	7.55	7.69	2.17	37.25	2.07	4.15	10.95
Occupation time	Ideal	23	20.62	1.80	17.42	25.00	2.07	19.83	21.42
	Real	23	25.50	5.94	17.42	38.58	2.07	22.87	28.12
Batch time	Ideal	15	32.08	3.49	26.05	38.25	2.14	30.08	34.08
	Real	19	41.43	11.54	28.05	72.75	2.10	35.71	47.14

Table 8. Results of the study time for the polyester resin Z3Z072

The first thing that attracts the attention is the elevated values of the batch times. To analyse them, the dead times and the occupation times are analysed.

Taking into account only the ideal dead time (to discard the weekends in the middle of a batch), the average of the times are 12.32 h and 6.84 h and the standard deviation 8.83 and 3.16 for the resins respectively, the resins pass too much time stopped in the dilution vessels. The possible causes are:

- The difference between the ideal and the real times of the filtration step for each resin indicates how many time is needed to replace a K.O. filter and start its regeneration. This problems affect the planning production and can lead to some delay.

  The filter K.O. depending on to many variables, for example, the times used or the purity of the resin before the filtration.
- The period of time between the unload of the resins to the dilution vessel and the control check of the head of operation is too long
- The time since the head of operation gives the confirmation of the final check until the filtrations start is too long.
- The staff is limited and it provokes a bottle neck in the filtration steps.

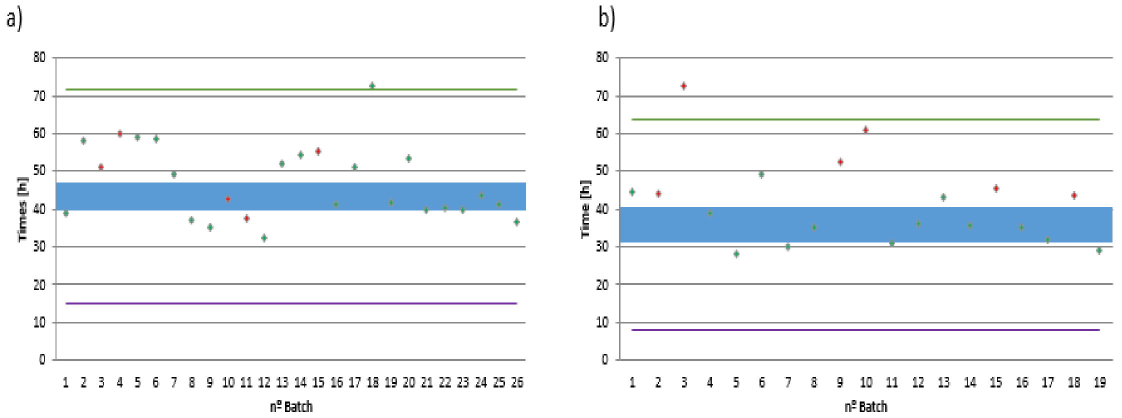
On the other hand, the occupation time presents a notable difference between the ideal and the real times. To evaluate the difference, each steps should be analysed in detail studying the process and evaluating in plant. The results of the tables 7 and 8, emphasize the difference between the ideal and the real time for the first step, raw materials and reactor conditioning. The incidents in this step are because the raw materials are not ready in their equipment when the resin should be started, drawing out the production batch process. Before drawing conclusions, it is recommendable to talk with the operators related with the operation to obtain information about the situation.

The reported incidents during the production process are include in the next table:

Kind of incident	Incident	Z2G130 Times	Z2G130 Total times [h]	Z2G130 Total time [%]	Z3Z072 Times	Z3Z072 Total times [h]	Z3Z072 Total time [%]
Logistic incidents	External from reactor	2	3.5	2.43%	4	30.0	22.42%
	Start of the plant.	4	5.0	3.47%	4	6.5	4.86%
	Load no prepared	11	24	16.67%	7	17.5	13.08%
	Filter not available	5	38.5	26.74%	1	14.5	10.84%
	Direct filtration	2	8.5	5.90%	-	-	-
	Personal shortage	2	18.0	12.50%	2	9.0	6.73%
	Incompatibility between technologies	1	2.0	1.39%	1	7.3	5.46%
	Punctual incidents	2	5.0	3.47%	-	-	-
	Plant stop	1	2.0	1.39%	-	-	-
Process incident	Yield	11	37.5	26.04%	10	47	35.13%

Table 9. Analysis of reported incidents

All the times studied in the tables 7 and 8 have been represented in a graphic with the range of 3 times the value of de standard deviation, also called 3 sigma (σ). To represent these graphics are considered the 3sigma using the ideal standard deviation and the real times for the batches. An example for the batch times of both resins are in next page:



a) Batch times for the resin Z2G130.
b) Batch times for the resin Z3Z072.

Red points: batches with some incident detected.
Green points: batches without incident.
Green line: Upper 3 sigma range.
Purple line: Lower 3 sigma range.

Figure 9. Real batches represented in the ideal 3 sigma range.

More information about the 3 sigma of each step in the Appendix II.

With all of this information, the project manager accepts the results and the valuation and focuses this project in the implementation of a new resin.

6. IMPLEMENTATION OF A NEW RESIN

AkzoNobel transferred a technology from England to Barcelona's site, and the new resin will be produced here.

The production of the new resin started in August of 2015 was agreed to last 30 h with the goal to reduce 10 % of the production process.

For the first 5 month the results are fared than a good results and it provokes delays in the deliveries. For this reason, it is urgent to analyse the new resin to identify the causes of the deviations.

6.1. Alkyd resins

Alkyd resins are produced by reactions of esterification and condensation polymerization. Alkyd resins are produced by reaction of an acid with an alcohol, it produce an ester and water, the difference between polyester resins are that alkyd resins contain oils (4).

Alkyd resins present the next properties:

- Alkyd resins are cheaper and easier to use.
- Alkyd resins dry faster tolerating easier excess work conditions.
- Isophthalic alkyd resins have high resistance to chemical agents and corrosion.

This class of resin is usable for:

- Topcoat paints.
- Alkyd resins are the binder of a lot of background paintings and the mixed oven enamel.
- In automotive industry the paints with alkyd resins dry at 130 ºC.

6.2. Z3A148 resin

The production process of the resin Z3A148 has 2 parts, the first part is produced in the reactor and the second part is produced in the dilution vessel. Each of these parts are divided in the following steps.

Reactor steps:

- First step. Load: this operation consists in loading the raw materials in the hopper and the deposits and activating the mixing of the reactor.
- Second step. Heating: the set-point of the mass temperature is programed and the process develops until it reaches the reaction temperature. This heating process is done in two steps, one until the boiling temperature of one raw material is reached, the second step takes place until the mass temperature reaches the set-point programmed. During this step the water and the solvent are distilled, the water is eliminated and the solvent comes back to the reactor, this operation is called reflux.
- Third step. Esterification: keeping the temperature of the reactor until the aid number and the viscosity of the resin is smaller than a characteristic value. There is reflux in this step.
- Fourth step. Cooling: cooling the reactor with cold thermic oil until a characteristic safety temperature.
- Fifth step. Second load: loading a raw material in the reactor.
- Sixth step. Second heating: the set-point of the mass temperature is programed and the process develops until it arrives to the reaction temperature. Start the reflux again.
- Seventh step. Second esterification: the same process than the third step, esterification. There is reflux in this step.
- Eighth step. Distillation: this resin does not contain solvent, the solvent is distilled.
- Ninth step. Second cooling: cooling the reactor first with cold thermic oil until a characteristic safety temperature, under this safety temperature the reactor is cooled by cooling water.
- Tenth step. Unload: unloading the resin from the reactor to the dilution vessel.

Dilution vessel step:

- Eleventh step. Filtration: filtration of the resin to remove all the defects and to collect the resin in a tank, drums, small tanks or tanker lorries.

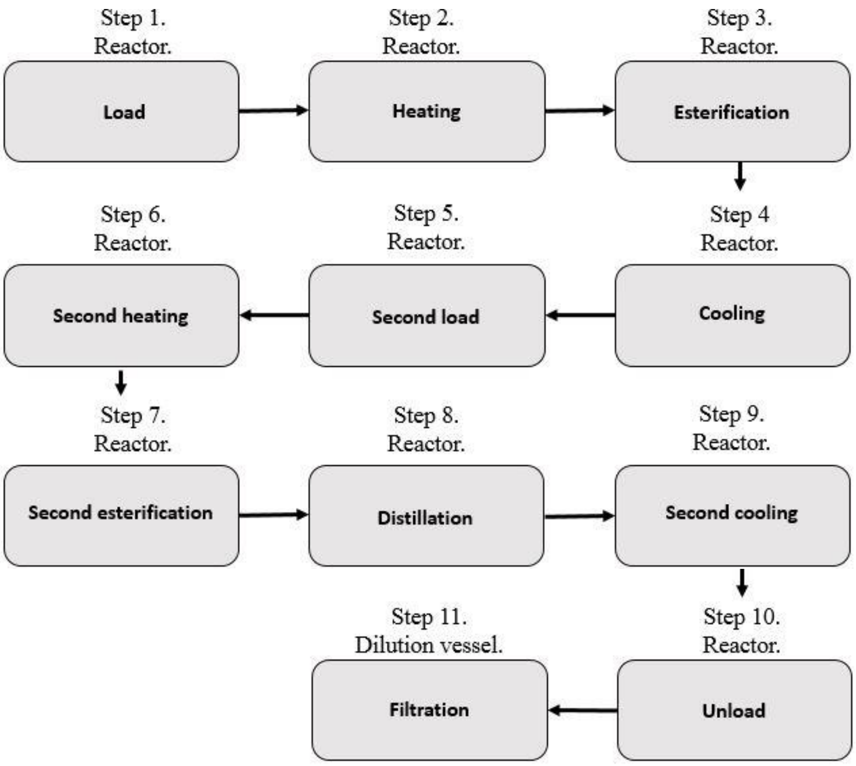


Figure 10. Operation diagram from the resin Z3A148

6.3. Time study and results

First of all, the information of all the batches for this resin is recollected in a data base. This data base is created to study the time for each step and the occupation time of the reactor. Incidents are included in the times, to obtain real results of the occupation time.

The resin Z3A148 is foreseen that will be important in the future production plan, specifically in the reactor 5. The results for the 24 batches from August until the 19th of November are:

Study time	Average [h]	Standard deviation	Batch with minimum time [h]	Batch with maximum time [h]	Confidence interval of 95% [h]	
					Lower	Upper
Load	1.60	0.81	0.33	3.82	1.25	1.95
Heating	7.57	1.72	4.17	10.80	6.82	8.31
Esterification	11.07	1.73	8.08	14.66	10.33	11.82
Cooling	0.94	0.30	0.50	1.75	0.81	1.07
Second load	0.22	0.12	0.08	0.50	0.17	0.27
Second heating	2.37	0.91	1.33	5.25	1.98	2.76
Second esterification	5.60	1.47	3.50	9.50	4.96	6.23
Distillation	3.21	1.27	1.33	7.08	2.66	3.76
Second cooling	2.19	0.89	1.17	5.25	1.81	2.57
Unload	1.99	1.39	0.83	6.75	1.39	2.59
Occupation time	36.66	3.27	31.33	43.93	35.25	38.07

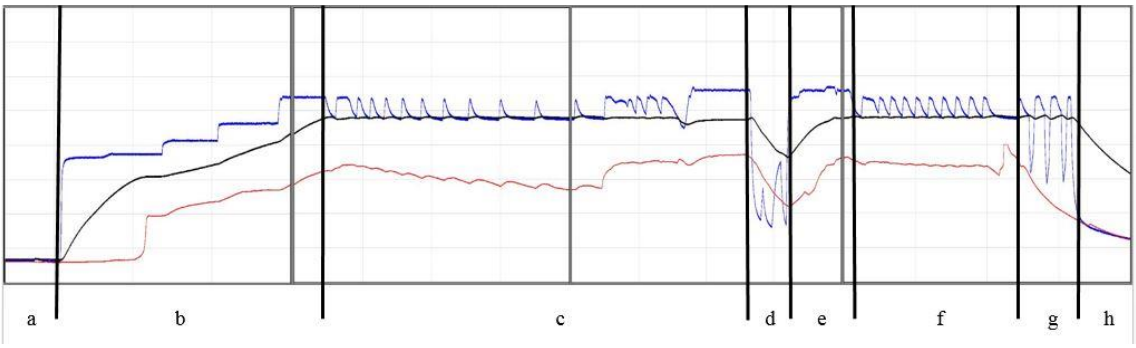
Table 10. Results for the study time of the resin Z3A148

The occupation time is far from the 30 theoretical hours and it presents a big standard deviation. To study the reason of this results, six steps have been selected for their results and they have been investigated:

- Load step: the average of this operation is very high. Incidents in this step usually are related to the production planning and the personal management.
- Heating and Esterification step: being a simple operation, the standard deviation is high. The next weakness have been detected:
  - High difference in the reflux between operators. The instruction process sheet reads “keep good reflux”. The interpretation of this command

varies from one operator to another. On the other hand, an operator should know what “good” reflux is.

- If there is too much solvent at the beginning of the reaction, the abundant reflux stems the heating of the resin. It is important to determine the enough amount of solvent at the beginning of the reaction to not stem the heating, but to be enough to stabilize the reaction faster.
- To study the stability of the process, the graphics production SCADA have been collected. These graphics show the mass temperature, the thermal oil temperature at the entrance of the reactor and the temperature of the vapours at the entrance of the condenser. These three variables allow to check if the reflux is constant or not during the resin process.



a) Load step.
b) Heating step.
c) Esterification step.
d) Cooling and second load steps.
e) Second heating step.
f) Second esterification step.
g) Distillation step.
h) Second cooling step.

Blue line: Mass temperature inside the reactor.
Red line: Thermal oil at the entrance of the reactor.
Black line: Vapour temperature at the entrance of the condenser.

Figure 11. Process representation. Example for a batch process

As it can be seen in the figure 11, the process is not stable and the reflux is not constant. The reflux is evaluated with these three variables. The only way to know if the reflux is constant is checking that the mass temperature, the thermal oil temperature and the vapour temperature are constant. That means: the mass temperature will be constant when the system is provided heat at the same time than the system is eliminating this heat by a gas flow in the reflux operation, and comes back cold and condensed.

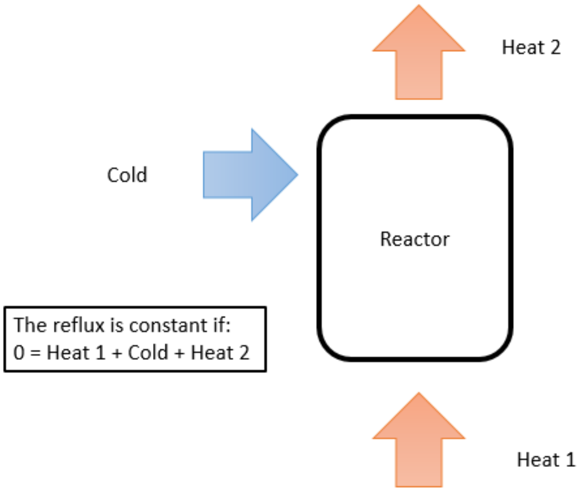


Figure 12. Sketch of reflux process

- Distillation step: the average time of this step is very high. This operation does not warn when it is over, if the operator does not pay attention, the resin will be in standby.
- Cooling step: this resin does not contain a solvent at the end of the process, so it can unload earlier.

6.4. Corrective measures

Considering the opinion of the operators, the head of operation, the personal of R&I resin department and the engineering department, the next actions are implemented:

- Educational background: discuss with the operators about the distillation operation and the reflux concept with its repercussion in the stability process
- Process monitoring: audit and give support to the production process in plant during the critical steps of the batch and determinate the initial solvent quantity.
- Team management: raise awareness on the operators about teamwork and let the loads ready before the batch start.

6.5. Results of the corrective measures

After the application of the corrective measures, the results of the same study time for 17 batches from 23th of November 2015 until January 2016 are:

Study time	Average [h]	Standard deviation	Batch with minimum time [h]	Batch with maximum time [h]	Confidence interval of 95% [h]	
					Lower	Upper
Load	0.76	0.33	0.08	1.25	0.58	0.94
Heating	6.21	1.36	4.17	8.50	5.49	6.93
Esterification	9.89	1.66	6.58	12.25	9.01	10.77
Cooling	1.00	0.30	0.58	1.67	0.83	1.16
Second load	0.20	0.11	0.08	0.50	0.14	0.26
Second heating	1.96	0.39	1.08	2.50	1.75	2.16
Second esterification	5.42	0.74	4.33	7.08	5.03	5.81
Distillation	2.27	0.87	1.42	4.92	1.81	2.73
Second cooling	1.25	0.27	0.83	1.83	1.11	1.39
Unload	1.23	0.81	0.58	3.67	0.81	1.66
Occupation time	30.19	2.82	26.49	38.75	28.69	31.68

Table 11. Results of corrective measures in the resin Z3A148

One the other hand, if the 3 batches with some important incident during the process are discarded, the study for the 14 ideal batches is in the next page:

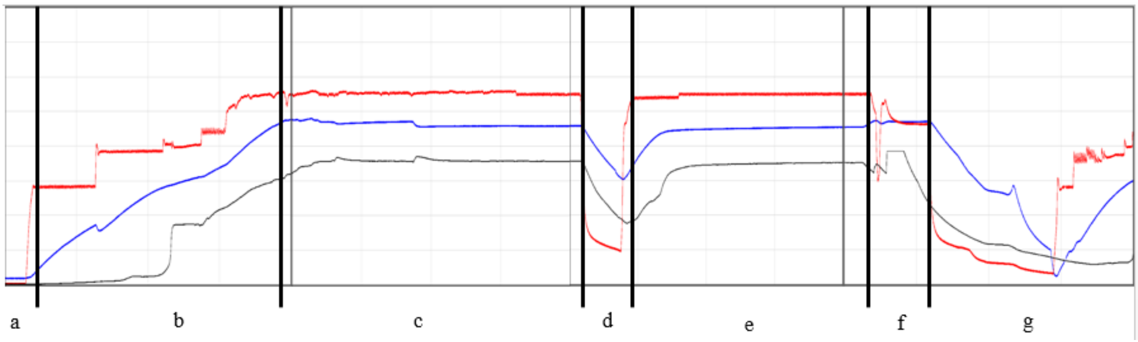
Study time	Average [h]	Standard deviation	Batch with minimum time [h]	Batch with maximum time [h]	Confidence interval of 95% [h]	
					Lower	Upper
Load	0.74	0.33	0.08	1.25	0.54	0.94
Heating	6.10	1.39	4.17	8.50	5.27	6.93
Esterification	9.39	1.38	6.58	11.92	8.57	10.22
Cooling	1.01	0.32	0.58	1.67	0.82	1.21
Second load	0.19	0.11	0.08	0.50	0.13	0.26
Second heating	1.99	0.34	1.50	2.50	1.79	2.19
Second esterification	5.32	0.65	4.33	6.25	4.92	5.71
Distillation	2.15	0.57	1.42	3.42	1.81	2.49
Second cooling	1.25	0.29	0.83	1.83	1.08	1.42
Unload	1.09	0.53	0.75	2.75	0.77	1.41
Occupation time	29.24	1.53	26.49	31.93	28.33	30.16

Table 12. Results of the corrective measures in the resin Z3A148 discarding the batches with important incidents.

The results of the table 11 and table 12 present a considerable improvement respect the results of the table 10. The occupation time achieves the condition of the 30 hours and there are batches of 27 hours, so the correction measures are in the right way.

The average of the critical steps has been reduced, as well as the standard deviation, so the corrective measures have reduced the occupation time and the variability in the process. The correction measures have produced the next changes:

- A planning of production is better and the problems with the loads are solved. The new results are acceptable.
- The knowledge of the operations allows to understand better the operations and its state in any situation. The average of the distillation step time is minor, but, there is a tendency to relax in this step. On the other hand, the conversations about the reflux have accomplished the following results.



a) Load step.
b) Heating step.
c) Esterification step.
d) Cooling, second load and second heating steps.
e) Second esterification step.
f) Distillation step.
g) Cooling and unload step.

Blue line: Mass temperature inside the reactor.
Red line: Thermal oil at the entrance of the reactor.
Black line: Vapour temperature at the entrance of the condenser.

Figure 13. Process representation. Example for a batch process

Figure 13 shows that the process is more robust respect before (figure 7), and the reflux is constant.

- Evidently, if the unload temperature is higher, the process will unload before. Therefore the time of the step is reduced.
- The solvent quantity in the load step is reduced 4 times. Checking the computer process and the equipment are observed if the process needs more solvent or not, and it can be added.

In the next table a compilation of the results are showed:

Before the time study		After the time study	
Time	Average time	Time	Average time
Load	1.60	Load	0.76
Heating	7.57	Heating	6.21
Esterification	11.07	Esterification	9.89
Cooling	0.94	Cooling	1.00
Second load	0.22	Second load	0.20
Second heating	2.37	Second heating	1.96
Second esterification	5.60	Second esterification	5.42
Distillation	3.21	Distillation	2.27
Second cooling	2.19	Second cooling	1.25
Unload	1.99	Unload	1.23
Occupation time	36.66	Occupation time	30.19

Table 13. Compilation of the results for the resin Z3A148 before and after the time study.

7. CONCLUSIONS

Independently of the results of this thesis, the most important thing of this project is the continuous improvement. Collecting information of the process in a data base and processing this data allows to have an image of the production planning and of the plant, these are important to detect the weaknesses of the process and to look for a solution. The weaknesses can be caused by personal management, production planning, lack of resources, etc. The vast majority of the weaknesses are camouflaged and it just shows the reflection of the real problem, for this reason is important to study step by step increasing the detail of the evaluating times. The general conclusions are:

- The experience studding information provides knowledge about how the values have to be collected to extract the maximum information.
- When a possible weakness is detected, it is important to evaluate the necessary time to study the causes, the possible costs to applicate the corrective measures and the time wined. The weaknesses that takes less time to correct and provides more time should be focused, most of these weaknesses are provoked for lack of formation and no work with the collected information about the production process.
- It is important to collect information talking with the personal of the plant and manage these information with the purpose to accelerate the detection of the weaknesses and application of the corrective measures.
- Evaluate the obtained results is important to know the state of the production process and the plant. This is the way to known if the real O.E.E. can be increased and how it will be done.
- A good information flow between the operators and the interne engineer has allowed to detect differences between the turns in the operation work. Correcting the differences with an understandable explanation makes the changes more attractive, of course it is important to support them during the change.
- The corrective measures in a process can be extrapolated to another process or just operations as reflux or distillations.
- The historical O.E.E. of the reactor 5 for the last month are in the next page:

R5	Month	August	September	October	November	December	January 2016
	OEE [%]	86%	79%	78%	78%	93%	85%

Table 14. Evolution of the O.E.E. for the reactor 5 from August 2015 until January 2016.

As it can be seen in the table 14, the O.E.E. presents a notable improvement since December of 2015.

This project is part of the continuous improvement process of the resin plant from AkzoNobel. In my opinion, the study of this project should not be stopped.

8. NOTATION

O.E.E.	Overall Equipment Efficiency.	[-]
Z2G130	A polyester resin.	
Z3A149	An alkyd resin.	
Z3Z072	A polyester resin.	
σ (sigma)	Standard deviation.	[-]

9. REFERENCES AND NOTES

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2. Bolsamania AEX. [Online] 2016, http://www.bolsamania.com/indice/AEX (accessed February 9, 2016).

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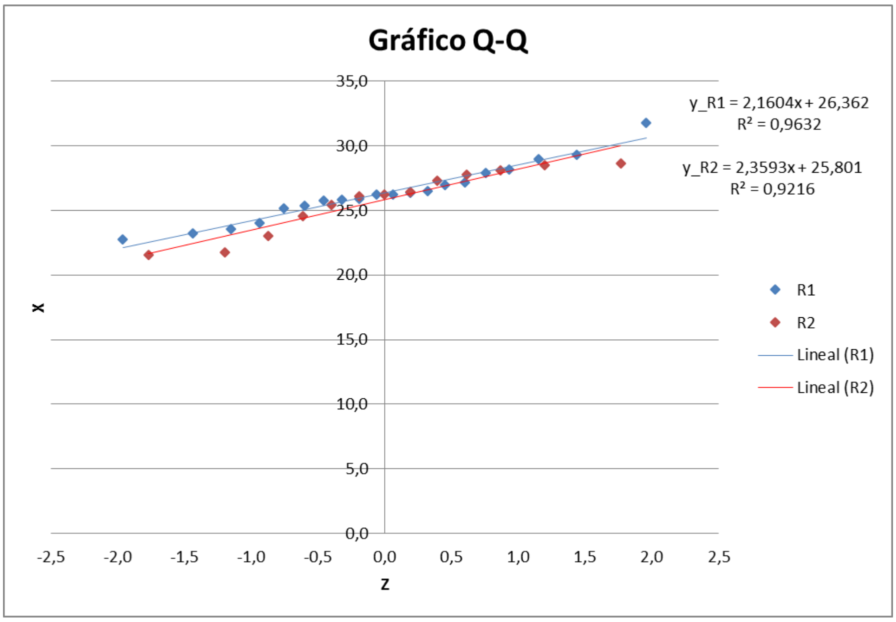
5. Murray R. Spiegel and Larry J. Stephens. Estadística Schaum. McGrawHill 2009; p 403.

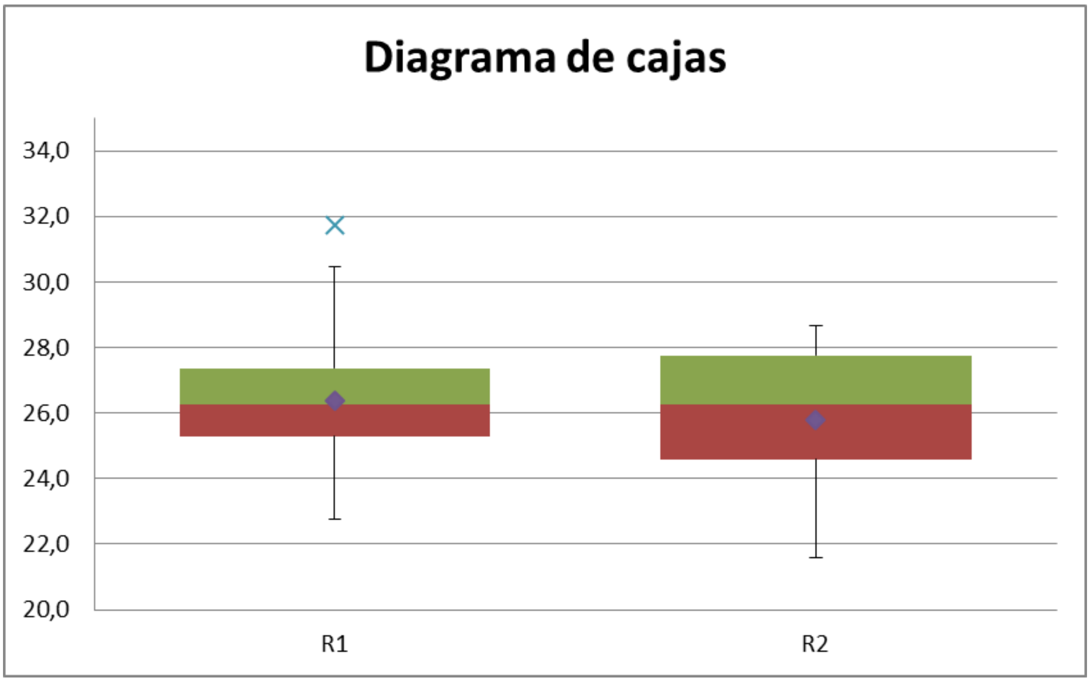
10. APPENDIX

10.1. APPENDIX I

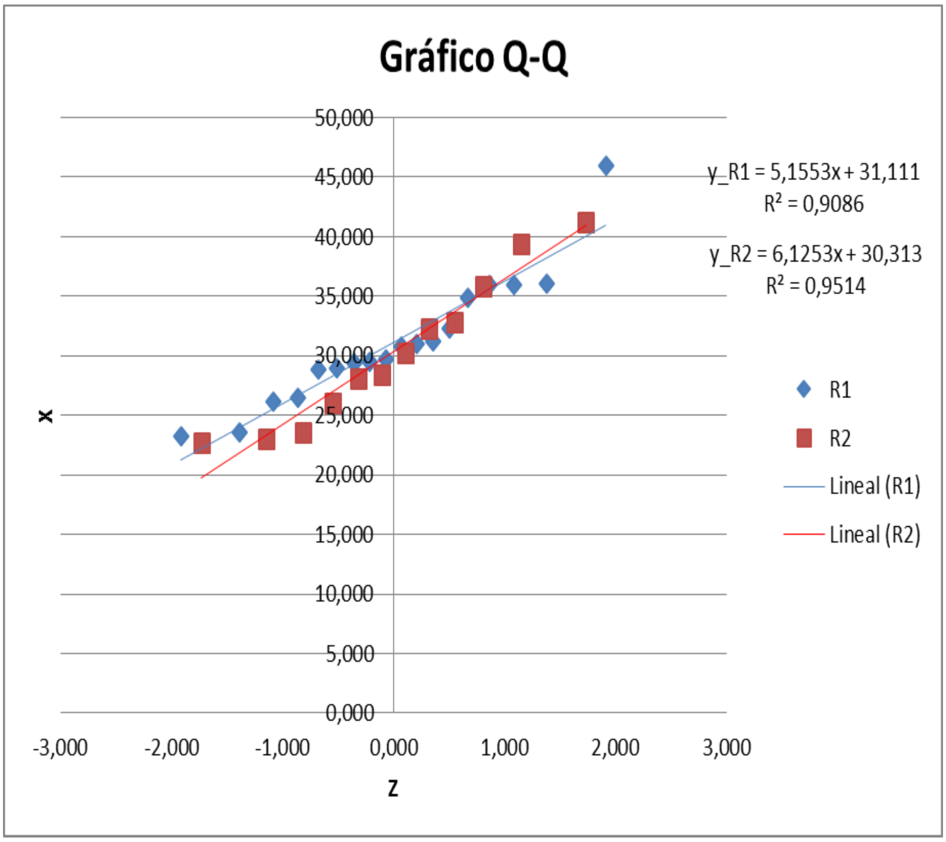
Q – Q plot of the ideal occupation time for the resin Z2G130



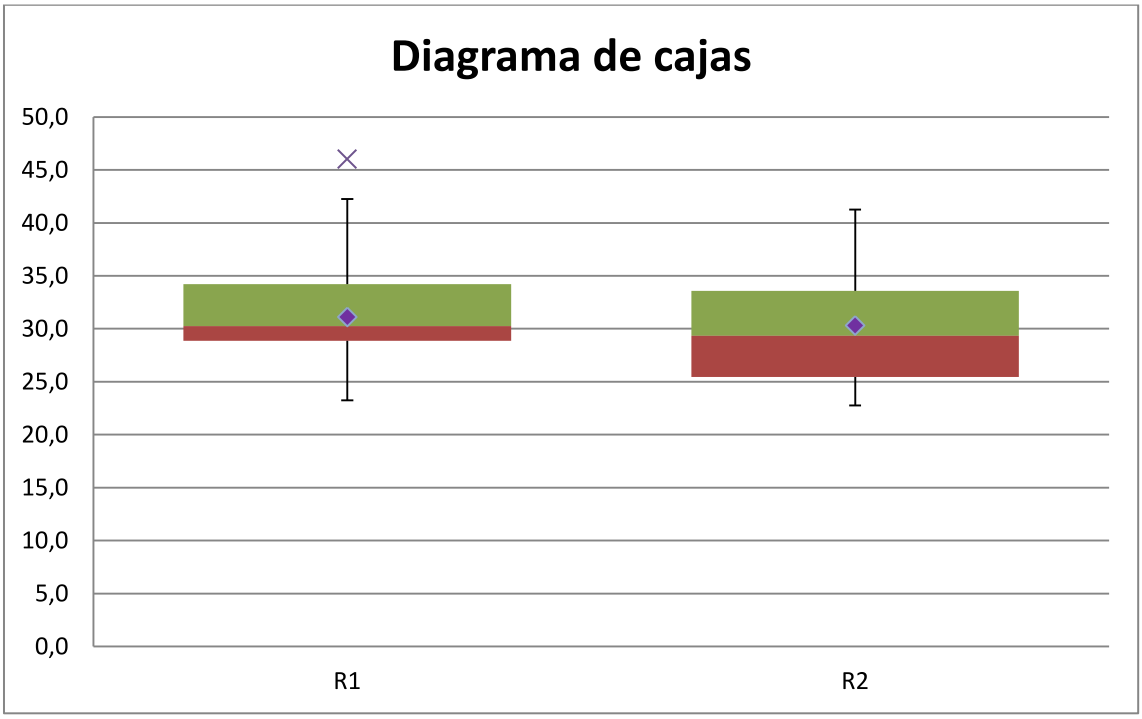
Boxplot of the ideal occupation time for the resin Z2G130



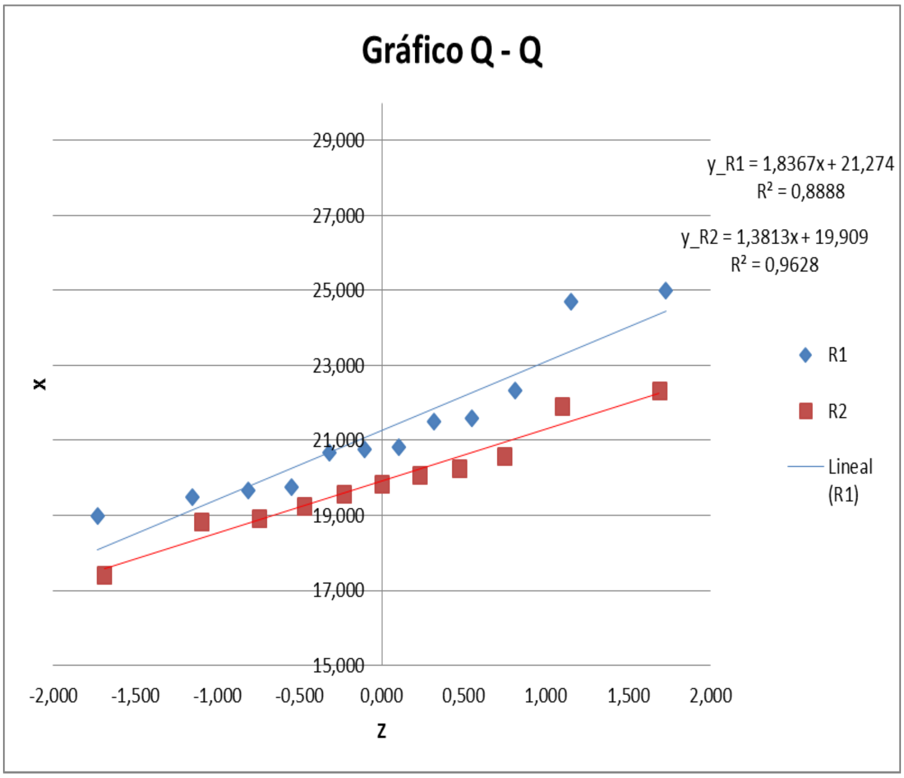
Q – Q plot of the real occupation time for the resin Z2G130



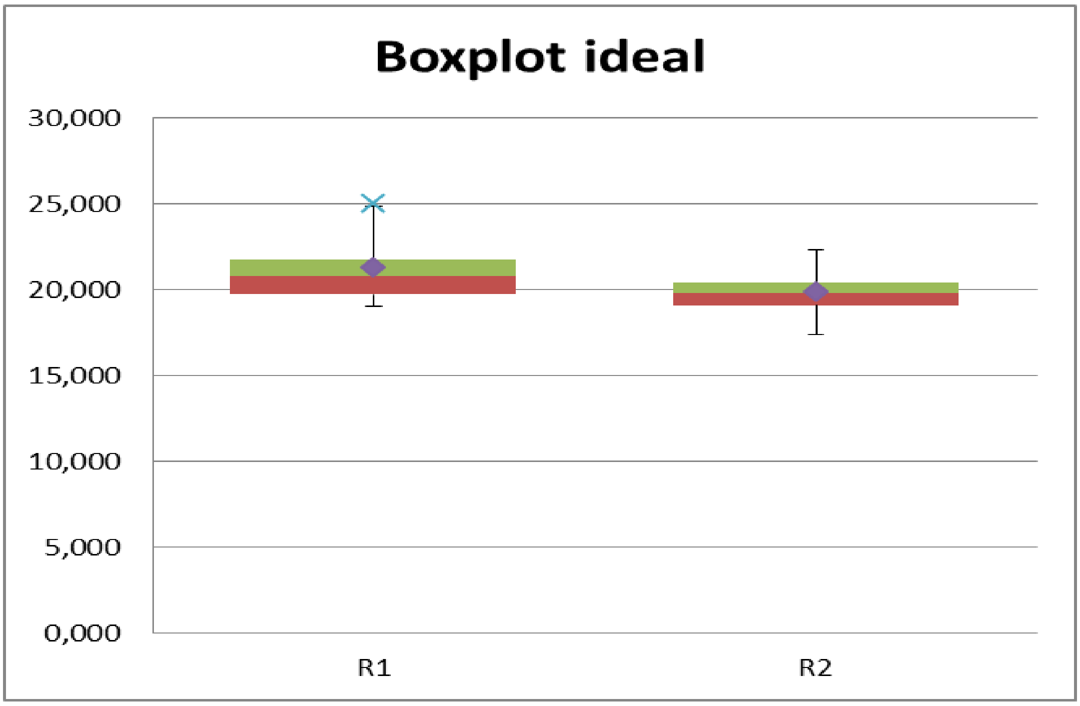
Boxplot of the real occupation time for the resin Z2G130



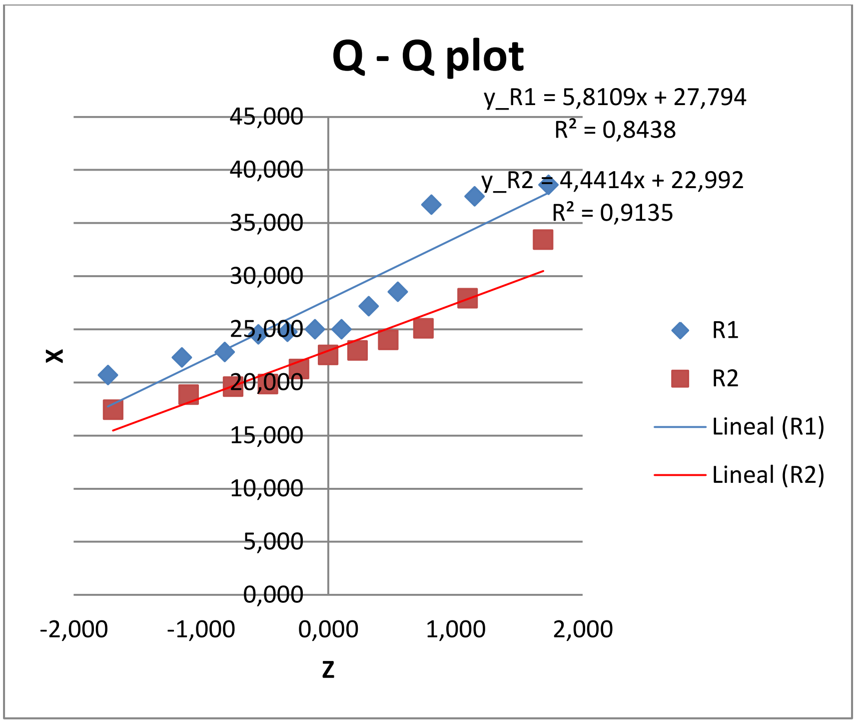
Q – Q plot of the ideal occupation time for the resin Z3Z072



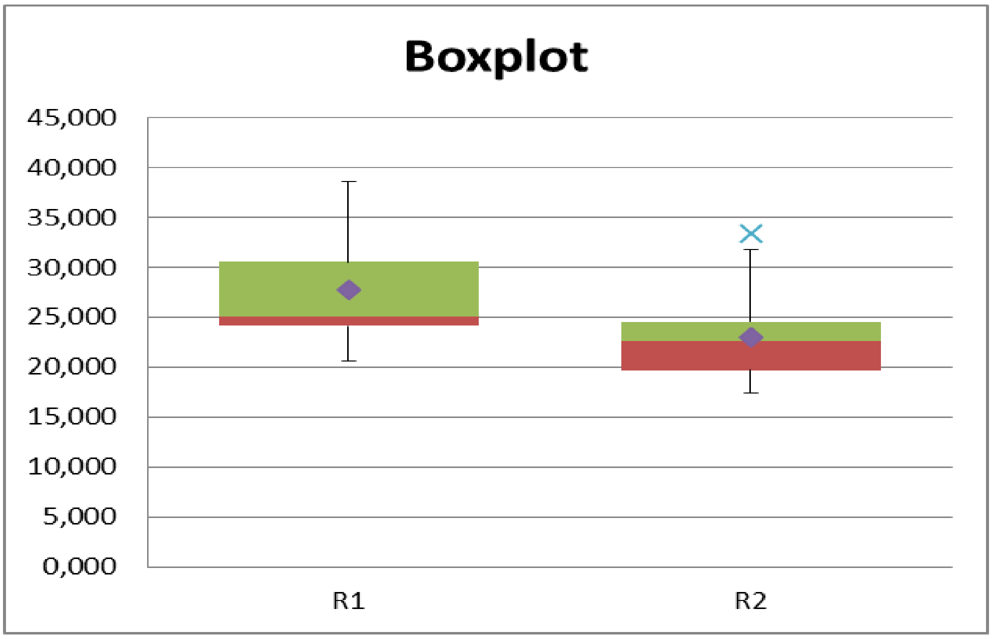
Boxplot of the ideal occupation time for the resin Z3Z072



Q – Q plot of the ideal occupation real for the resin Z3Z072

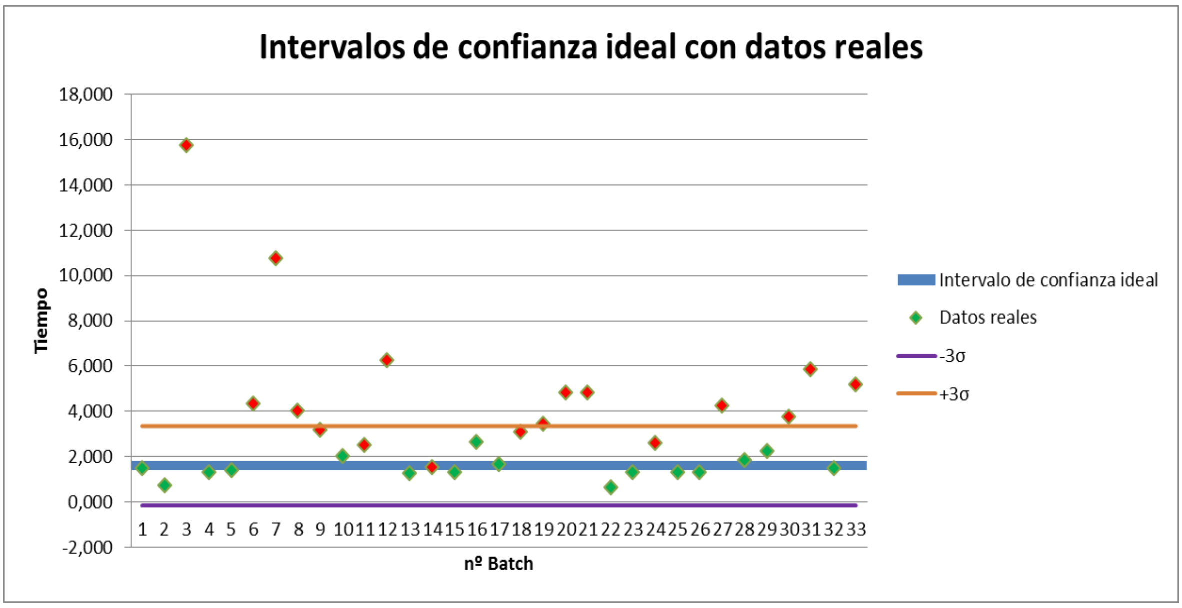


Boxplot of the ideal occupation real for the resin Z3Z072

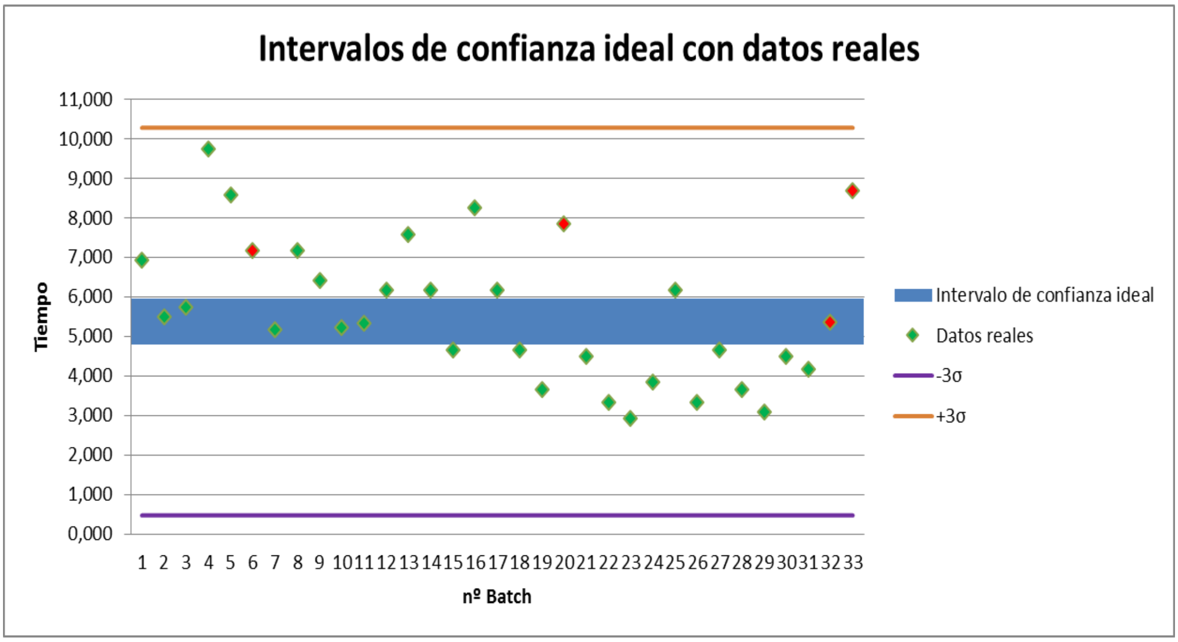


10.2. APPENDIX II

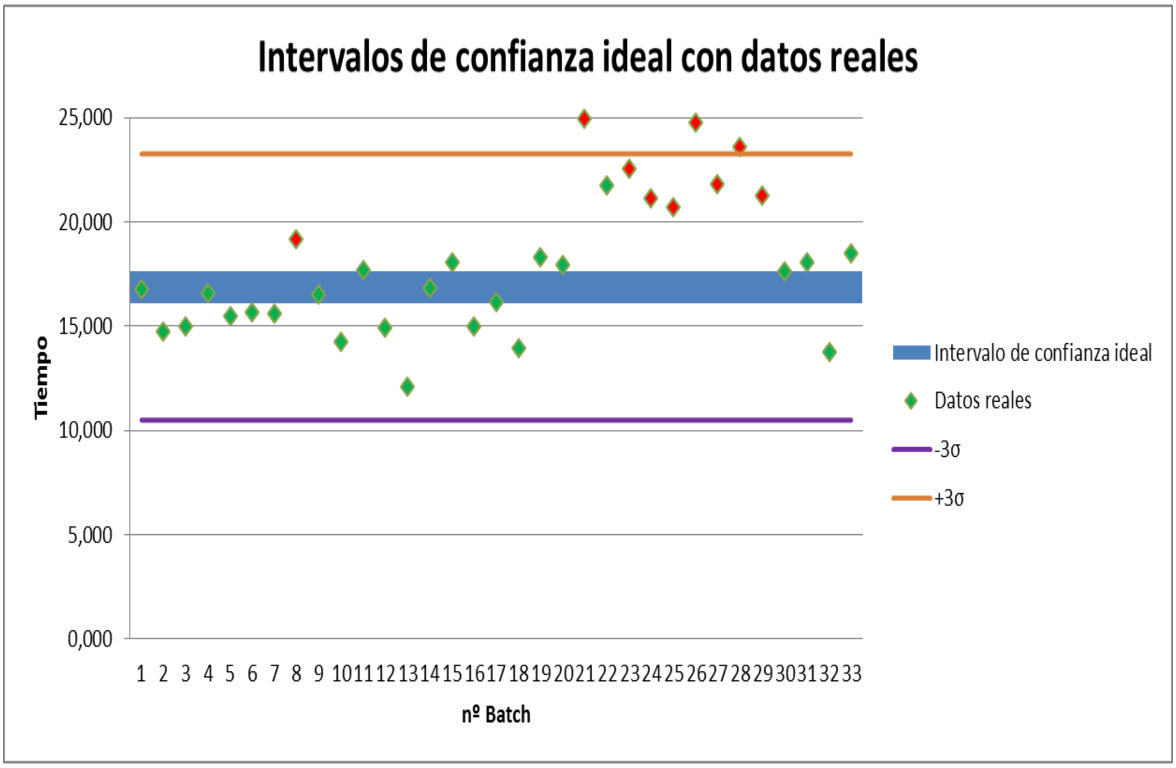
3 sigma range for the real batches of the step 1 resin Z2G130



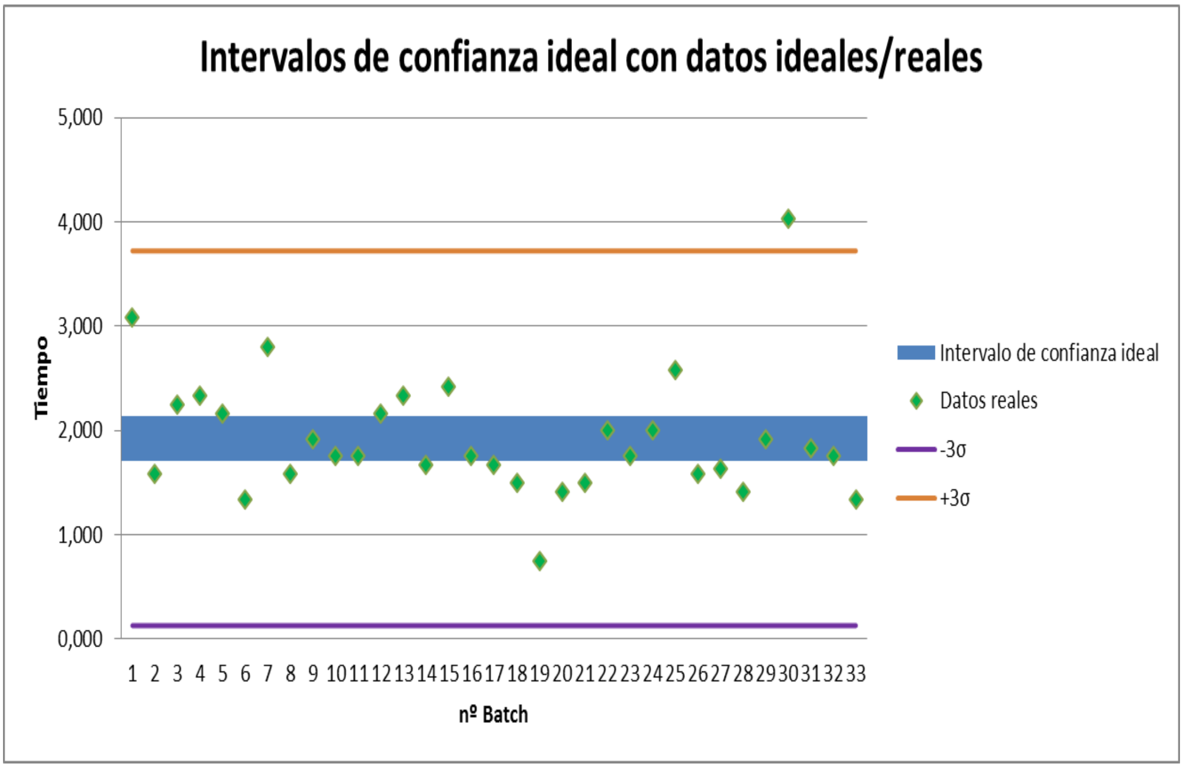
3 sigma range for the real batches of the step 2 resin Z2G130



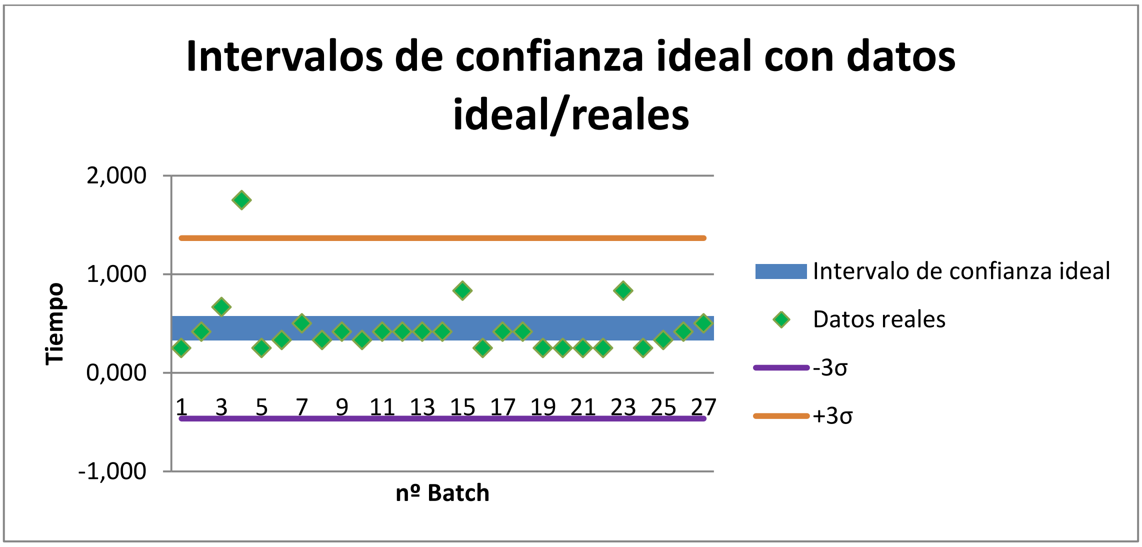
3 sigma range for the real batches of the step 3 resin Z2G130



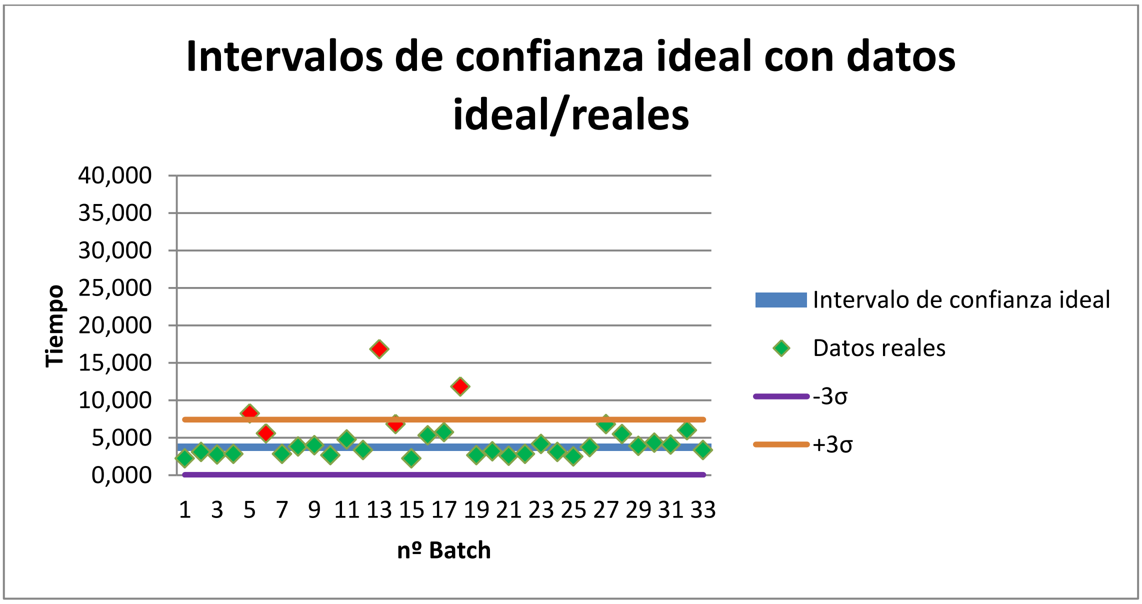
3 sigma range for the real/ideal batches of the step 4 resin Z2G130



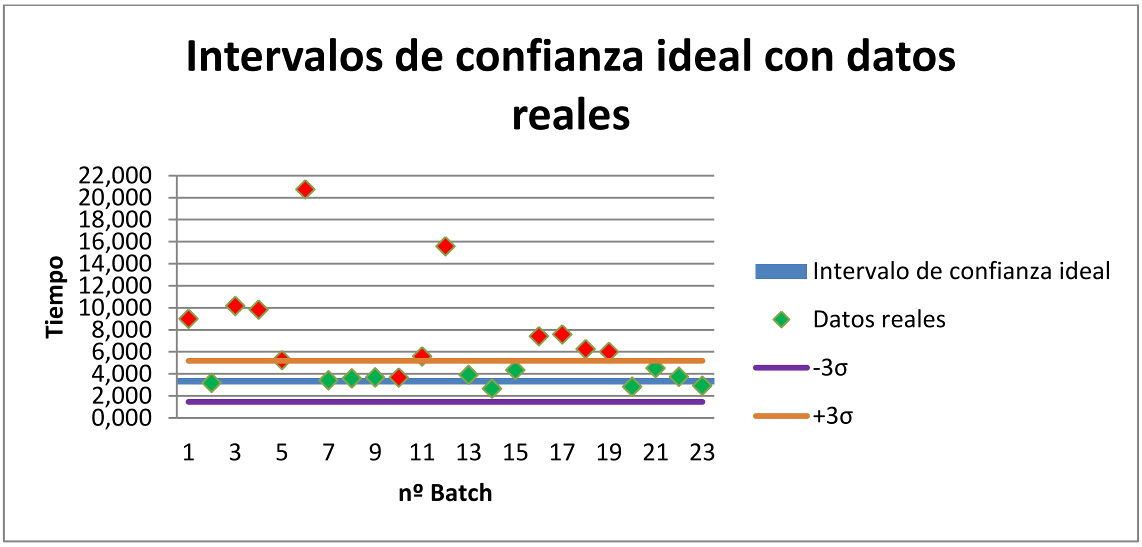
3 sigma range for the real batches of the step 5 resin Z2G130



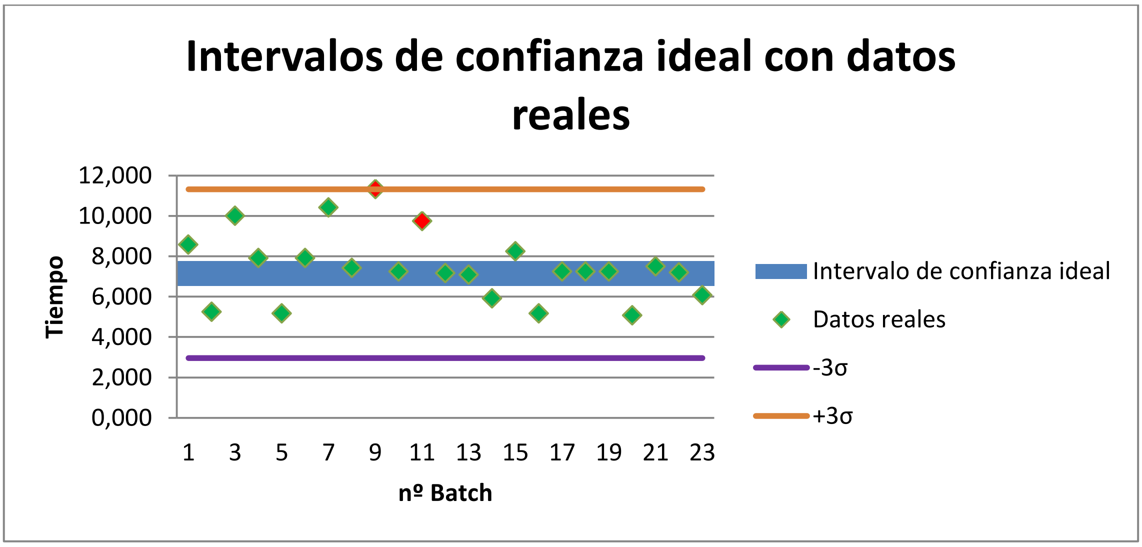
3 sigma range for the real batches of the step 6 resin Z2G130



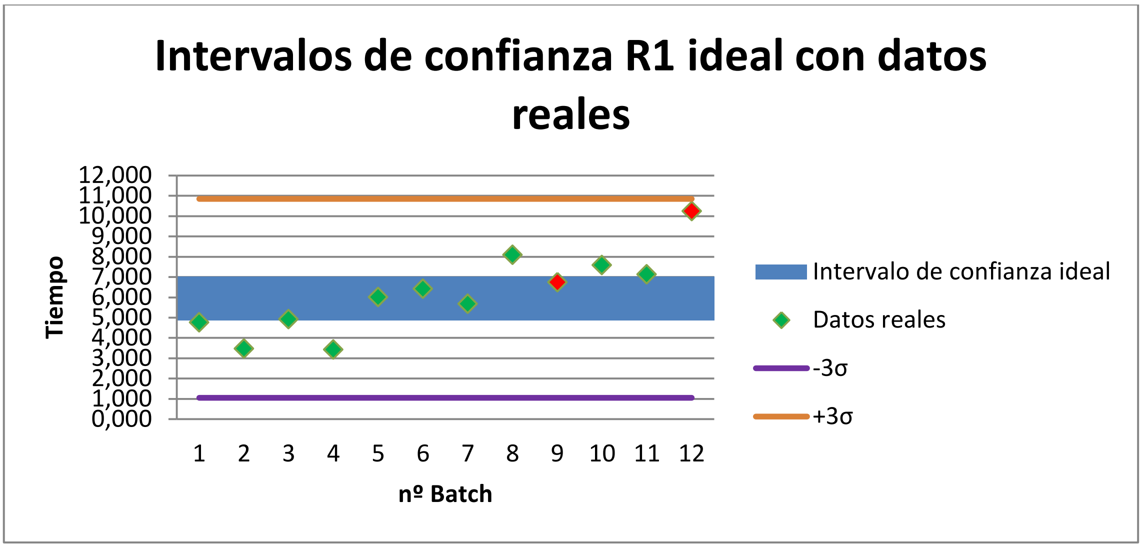
3 sigma range for the real batches of the step 1 resin Z3Z072



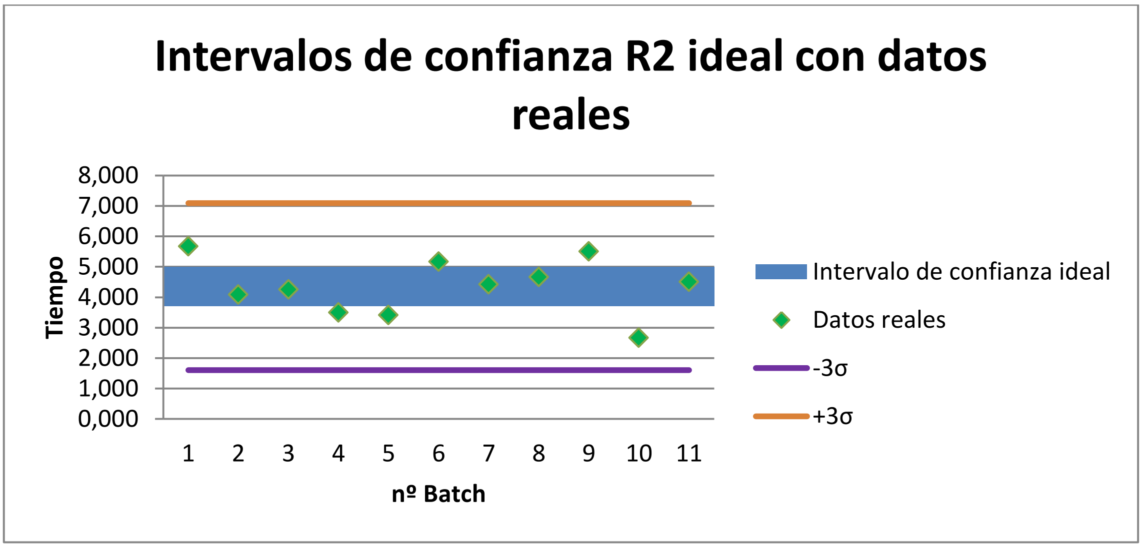
3 sigma range for the real batches of the step 2 resin Z3Z072



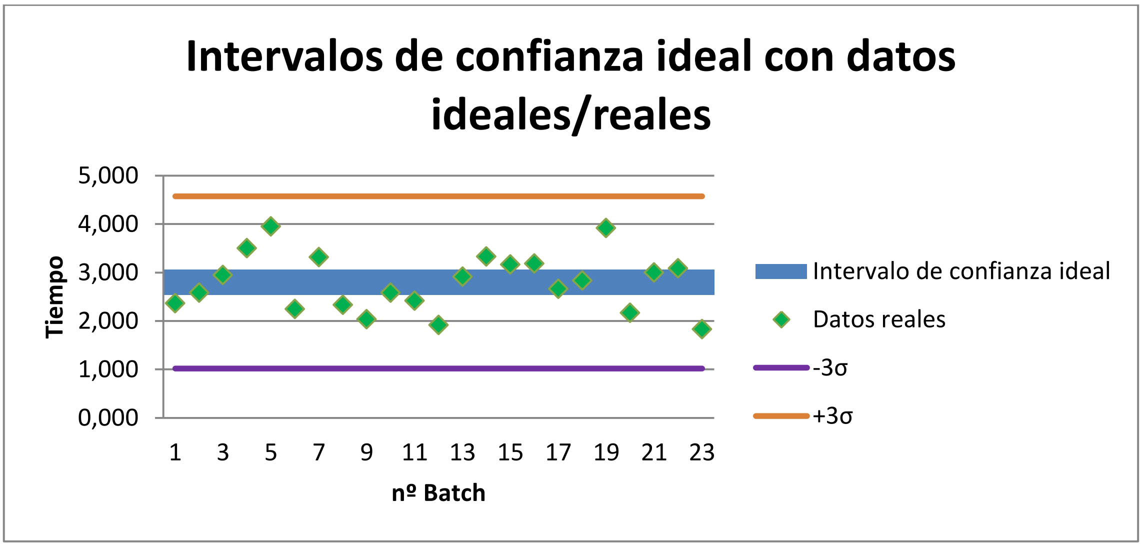
3 sigma range for the real batches of the step 3 resin Z3Z072 for reactor 1



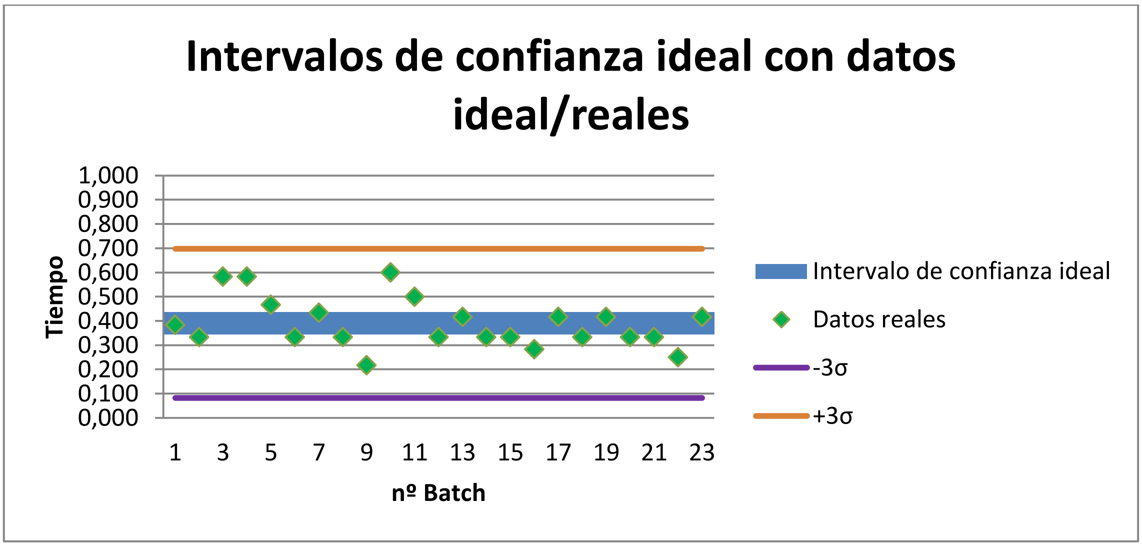
3 sigma range for the real batches of the step 3 resin Z3Z072 for reactor 2



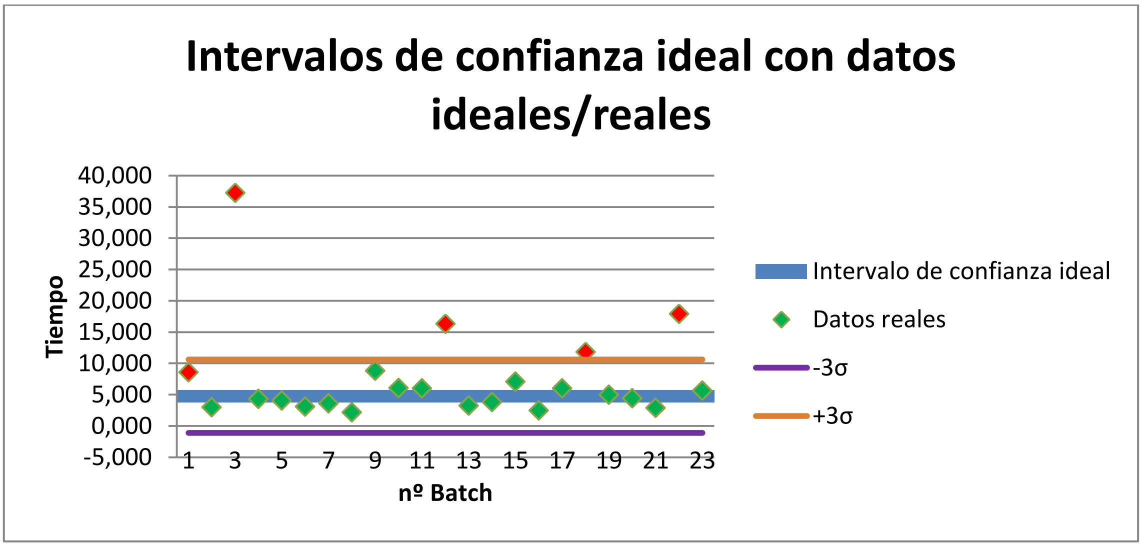
3 sigma range for the real batches of the step 4 resin Z3Z072



3 sigma range for the real batches of the step 5 resin Z3Z072



3 sigma range for the real batches of the step 7 resin Z3Z072



3 sigma range for the real batches of the step 6 resin Z3Z072