Redesign of Washing Process of Cartridge Case Using a Combination of Acids, Detergents and Anti-tarnish Compounds

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The current study establishes the conversion from a washing process of cartridge case performed by batch to a continuous process. The materials used during the wash process were a combination of substances such as acids, detergents and anti-tarnishes. Methodologies like Retrofit Design Approach and Hierarchical Decision Procedure by Douglas were combined for: 1) determining input Information, 2) developing diagnosis and identifying improvement proposals, 3) establishing input – output structure of the flowsheet, 4) defining critical variables of the process (CVsP), and 5) designing new units that support the change from batch process to continuous process.   The objective of that combination of methodologies was to solve the complex interactions between unknown variables values. The process critical variables identification was made using a method based on analysis of wicked problems. The result of that, determines that pH and temperature were critical for the process and the detergency efficiency and foam density were critical for the quality. A new continuous process was proposed and represented in a Process Diagram Flow. The redesign reduced problems like poor quality generated by lack of standardization, energy losses and ergonomic and safety risks. The results showed the combination of methodologies and the utilization of a method based on analysis of wicked problems instead of using an optimization method for identifying CVPs was effective to provide consistent and viable solution and support for decision-making at implementation phase.

1. Introduction

In order that a process guarantees high quality products according with the changes of market forces, it is necessary to improve the process design with update purposes, through an effective evaluation and deep data analysis of its design variables. The improving phase normally consists of incorporate new technology that minimizes production times, guaranties workers' safety and health, and a high productivity. A well-known methodology called Retrofit is usually applied for redesigning chemical processes, which considers modifications and adaptions of new components, with the objective of minimizing the process changes and maximizing the use of existing equipment and devices. Unfortunately, when a process simultaneously involves numerous design variables, the methodology provides several solution alternatives (Rodríguez, 2005), and many of them are unviable for implement it. Thus, the interactions between design variables are critical. A methodology that reduces the complexity of original models is the Retrofit Design Approach - RDA (Hernández *et al.,* 2011). It consists of three main stages: 1) diagnosis, where the key design variables should be selected, 2) evaluation, where the favourable options that were selected from the diagnosis stage are investigated and 3) optimization, where the optimal values are obtained according with the ranges of parameters required (Lavric, 2013). On the other hand, synthesis activity is complicated because there are many ways to accomplish the same goal. Hence, the Hierarchical Decision Procedure by Douglas (HDP) for conceptual design of chemical processes is a systematic approach for reducing design problem. The HDP applies hierarchy of decisions, using the flowsheet structure at successive levels of detail (Douglas, 1988). At last, the decision-making about implement the redesign was determined when the proposal achieves the

objectives, and the cost of investment is viable. Therefore, there is not a single company that invests in a process redesign that has various solution alternatives. In fact, it only needs the most optimal and viable solution for implementing in real conditions, with the less possible cost that guarantees high quality products.

The current study, proposes the redesign of a cartridge case washing process performed by batch, which uses a combination of acids, detergents and anti-tarnish compounds. The design objective was to change the washing process performed by batch for a process that operate continuously. As result a conceptual design was proposed. The existing batch process flowsheet was used as input information, moreover the analysis was made through RDA and HDP. The design critical variables identification was developed based on methodology for resolving wicked problems. Considering the redesign as a wicked problem (Buchanan, 1992), in other words as a problem inaccurately formulated, where the information was confused with conflicted values, from different clients and decision-makers, and the whole system are thoroughly unclear.

2. Problem statement

The manufacturing process of rifle bullet casings consists on nine steps, and at the end of each one the product requires to be washed. Thus, the washing is one of the most important process elements during the production of cartridge cases, and it is essential for granted high quality products. The washing process improved in the present work, have been performed by batch and manually handled for a long time (more than 60 years). For carried out the cartridge case washing, the operator mixed different solid components and aqueous solutions such as acid, detergents, and anti-tarnishes. The chemical mixtures were prepared into a barrel of 200L of capacity; the components were slowly added by hand into 180L of water using a plastic bucket and the mix was heating by dipping a pipe with steam. The washing procedure is showed on Table 1. The washing objective is to remove the residues of lubricant, which was used during draw process, as well as clean off the tarnishes over the metallic surface that were generated during manufacturing operation. The workers wore only a coverall and plastic gloves as personal protection equipment to develop the task, and they did not wear protective gas masks, resulting on a exposure to the mixture of acid gases remained on the workstation during the full shift. The company has identified two problems to solve: 1) poor quality of washing caused by non-standardized work method, 2) exposure of the personnel to ergonomic risk, unsafe and unhealthy work conditions.

Table 1: Washing procedure

Step 1: Solution preparation
Barrel 1: mix powdered detergent with water, heat the mixture with steam
Barrel 2: mix powdered degreaser with water, heat the mixture with steam
Barrel 3: mix acid solution 1 with water. Add the acid slowly using a plastic bucket.
Barrel 4: mix acid solution 2 with water and anti-tarnish. Use a plastic bucket.
Total batches by mix 4 with equivalent to 800L consumed by shift
Step 2: Fill washing tank with a batch of cartridge cases
Step 3: Add solutions to washing tank
Note 1: The mix temperature and heating time are not determined; the operator heats the mixture by dipping a pipe with steam until the barrel is empty.
Note 2: The component proportions have been omitted as request of the company.

3. Hierarchical design methodology based on retrofit for washing process of cartridge case

From hierarchical decision procedure (HDP) were only considered two stages: input-output structure of the flowsheet and batch versus continuous, the rest of levels were not considered due they are not necessary for the process. Moreover the requirements analyses for flowsheet conceptualization were developed in base of Turton recommendations (Turton *et al*, 2009). From the retrofit design approach (RDA), only were considered: diagnosis and evaluation, nevertheless for diagnosing and evaluating the critical process variables (CPVs), the method "Determination Matrix for CPVs" was used (Contreras, 2011).

3.1 Diagnosis
    1.   Diagnosis about batch operation method
    2.   Process variables identification from the batch washing process

3.2 Input Output structure of flowsheet
    1.   Development of Input-output flowsheet for the batch washing process: it includes conceptualization and analysis of the process, process topology, stream information and equipment information as follow:

      a.   Establish input and output streams
      b.   Determine stream characteristics
      c.   Identify equipment
      d.   Locate auxiliary equipment for power and heat generation

3.3 Evaluation

1. Evaluate the process variables using CPVs – Determination Matrix as follow:
   a.   By experts about the process define which process variables meet the follow requirements:
      i.   Corresponds to Input – Output structure
      ii.   Is independent variable,
      iii.   It affects the production volumes,
      iv.   It impacts on the equipment operation,
      v.   It is present during the whole process
      vi.   It impacts the operation time, the product quality and productivity indices.
   b.   The matrix columns are building by alternatives that represent the variables.
   c.   The rows characterize criteria described above.
   d.   A weight is assigned as criterion value (see Figure 2 and 3). The highest value represents the CPVs.

3.4 Batch vs Continous

1. Batch versus Continuous: a comparison of a batch process design to a continuous process design should be made.
2. Proposal of Redesign

4. Results and Discussion

The results from batch process were summarized in the process diagram flow (PDF) showed in Figure 1. Four main pipes represented the input structure; they distributed steam and cool water in an independent way to the barrels and washing tanks. The pipes were identified from 1 to 4: pipes 1 and 3 contain steam; pipes 2 and 4 contain cold water. There were not pipes between barrels and washing tanks, thus the mixtures supply from barrels to washing tanks was carried out by hand. The draining of mixtures from the washing tank to the water treatment plant represented the output structure, and it was identified with number 5.   All the equipment was identified and numbered, the services equipment for heating generation was not represented in the PDF due it was located outside of the washing area. Finally all process variables were identified.
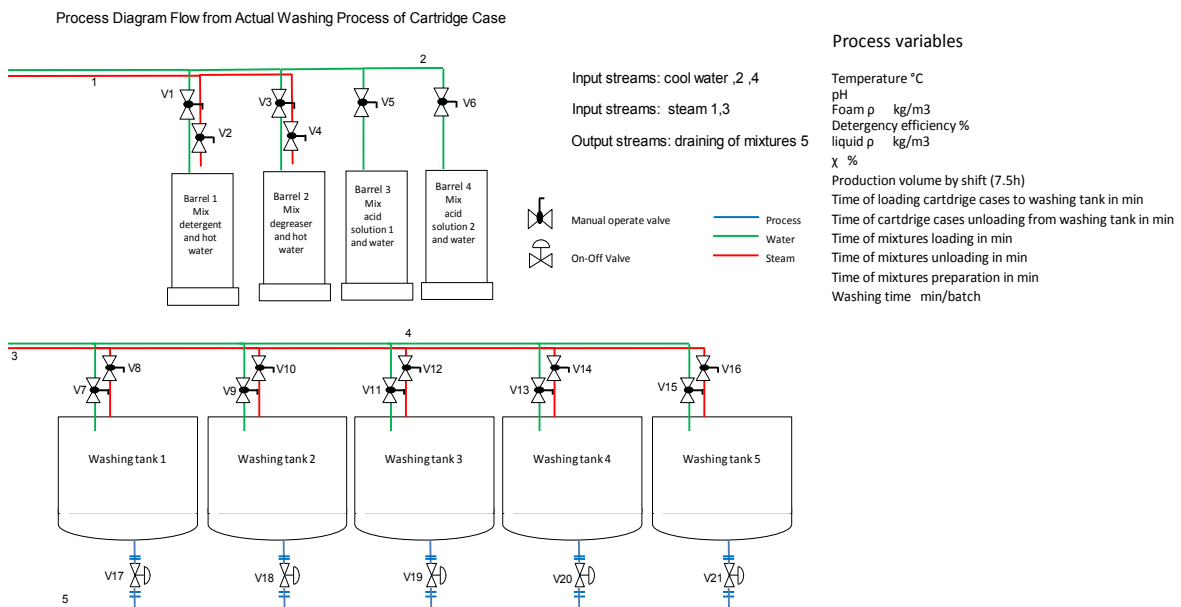

Figure 1: Process diagram flow of batch process from cartridge case washing

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During the evaluation of batch process variables using CPVs – Determination Matrix (see Figure 2), only seven process variables were selected for to be evaluated: materials pH (detergent, degreaser and acid solutions), temperature of water °C, foam density kg/m^3, detergency efficiency %, liquid mixture density kg/m^3 and concentration %. The criterion value was assigned by the process experts, in base of production and quality importance. After the analysis and evaluation of batch process, the results were the following: materials pH were the critical process variables, unfortunately the pH value was unknown during the process of redesign, to be specific, it was always unknown not because it cannot be determined, in spite of it was the most important value of the process, simply the company decided to keep it as industrial secret. On the other hand, foam density and detergency efficiency were on second place due to both variables were critical to quality. The diagnosis and Identification of variables for the process redesign was made using the same determination matrix, but in this case the variables were evaluated thinking in a continuous process, see Figure 3. After the analysis and evaluation, the results were the following: again, materials pH were the critical process variables and temperature and flow rate were on second position as common in continuous process. However, foam density and detergency efficiency were on fourth place. That result represented an inconsistency due to high foam density is necessary to guarantees high quality products, but at the same time high foam density represented a system restriction attributable to it could block the stream flow from the water and detergent mixture. Thus, in order to solve that situation, a study about equilibrium point between foam density and detergency was carried out; with the intention of prevent blockages in the streams flow.

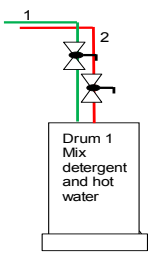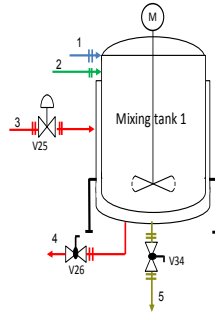| Critical Variables of Process (CVsP) - Determination Matrix															
Alternatives									Results Chart - Results Table						
Criteria	pH	T$_{in}$ °C	Flow rate kg/s	Foam ρ kg/m3	Detergency efficiency %	liquid ρ kg/m³	χ %	Criterion value	pH	Tin °C	Flow rate kg/s	Foam ρ kg/m3	Detergency efficiency %	liquid ρ kg/m3	χ %
Corresponds to Input – Output structure	x	x				x		2	2	2	0	0	0	2	0
It is independent variable	x	x						1	1	1	0	0	0	0	0
It affects the production volumes	x			x	x	x		3	3	0	0	3	3	3	0
It impacts on the equipment operation	x							4	4	0	0	0	0	0	0
It is present during the whole process	x	x		x	x	x		1	1	1	0	1	1	1	0
It Impacts the operation time	x	x		x	x			4	4	4	0	4	4	0	0
It impacts productivity indices	x			x	x			4	4	0	0	4	4	0	0
									19	8	0	12	12	6	0
									selected critical variable						
EVALUATION									X						

Figure 2: Critical Variables of Process (CVsP) – Determination Matrix from batch process

Critical Variables of Process (CVsP) - Determination Matrix															
Alternatives									Results Chart - Results Table						
Criteria	pH	T$_{in}$ °C	Flow rate kg/s	Foam ρ kg/m3	Detergency efficiency %	liquid ρ kg/m³	χ %	Criterion value	pH	Tin °C	Flow rate kg/s	Foam ρ kg/m3	Detergency efficiency %	liquid ρ kg/m3	χ %
Corresponds to Input – Output structure	x	x	x			x	x	2	2	2	2	0	0	2	2
It is independent variable	x	x	x	x	x			1	1	1	1	1	1	0	0
It affects the production volumes	x	x	x	x	x	x	x	3	3	3	3	3	3	3	2
It impacts on the equipment operation	x	x	x					4	4	4	4	0	0	0	0
It is present during the whole process	x	x	x	x	x	x	x	1	1	1	1	1	1	1	2
It Impacts the operation time	x	x	x			x		4	4	4	4	0	0	4	0
It impacts productivity indices	x			x	x		x	4	4	0	0	4	4	0	2
									19	15	15	9	9	10	8
									selected critical variable						
EVALUATION									X						

Figure 3: Critical Variables of Process (CVsP) – Determination Matrix from continuous process

The comparison established in section 3.4 batch versus continuous was developed in a table with the same name, an example of the results is shown in Table 2. The first column enclose the draw of one barrel from batch process, the second column describes the features needed for the operation, the third column include a draw of the mixing tank proposed as redesign for the continuous process, finally the fourth column contains an example of the equipment characteristics required by the continuous process. The results about mass and energy balance, sensitivity analysis, process capability, determination of equipment materials, among others are omitted in the present work as request of the company. During the redesign of the washing process the principal and auxiliary equipment, requirements of services about steam, water, electricity and air, piping and instrumentation were determined in order to reach the automation of the operation through Programmable Logic Controller (PLC). The automation allowed to standardize the process and eliminated the hazards and risks conditions, increasing the process productivity. Part of the redesign is showed in the Figure 4.

Table 2: Batch versus Continuous

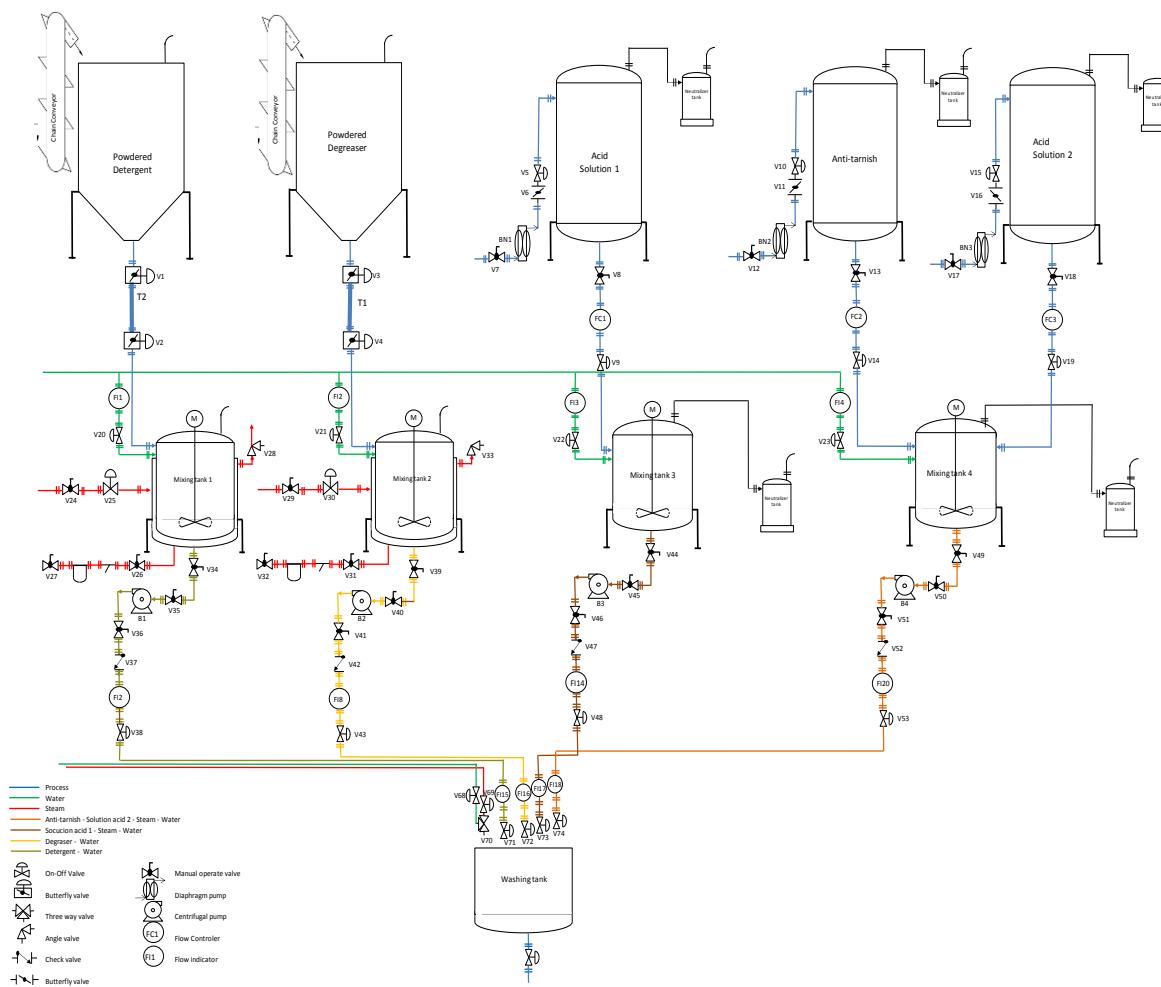| Batch process		Continuous process	
Equipment	Description	Equipment	Description
Drum 1	Operation: Mixing detergent and hot water	Mixing tank 1	Operation: Mixing detergent and hot water.
	Plastic drum 200L of capacity 2 pipelines of stainless steel SS316 1"diameter. 2 manual operate valve Stream 1 for cold water Stream 2 for steam Temperature unknown pH unknown Density unknown		Stainless steel SS316 tank mixer of 2m height per 0.8m diameter 5 pipelines of stainless steel SS316 1.5"diameter. 2 manual operate valve 2 on-off valves Stream 1 detergent Stream 2 cold water Stream 3 steam input service Stream 4 steam output service Stream 5 mix of detergent and hot water T_{in} 85°C pH known Density known

Figure 4: Partial Process diagram flow of continuous process from cartridge case washing.

5. Conclusions

The hierarchical design methodology based on Retrofit for Washing Process of Cartridge Case allowed the conversion from a washing process of cartridge case performed by batch to a continuous process. During the definition of critical variables of the process (CPVs), the results from the evaluation established that the materials pH were the critical variables of process, nevertheless was unknown during the process performance, therefore, was found an inconsistency that was resolved with the redesign. The detergency efficiency and foam density were defined as critical for the quality. Finally, the Process Diagram Flow proposed was effective to provide consistent and viable solution to standardization and risk elimination proportioning support to the decision-making done by the company.

Acknowledgments

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