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METHOD OF ANALYSIS AND TROUBLESHOOTING APPLIED IN THE TREATMENT OF SEVERE CORROSIVITY IN AN UNDERWATER PIPELINE

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ABSTRACT

The dynamics involved in the process of oil extraction in the offshore environment involves pipeline meshes interconnecting wells to platforms and these to relief ships, allowing the productive flow realized. As an offender in this marine environment, salinity characteristic of water is a source of corrosion in the pipelines that make up the underwater production chain. The present work sought to treat the specific case of a submarine pipeline that presents severe corrosivity that could cause serious environmental damages, as well as the impact of the image of the organization responsible for oil extraction. Based on this systematics, the objective was to identify the responsible causes for undesired occurrence, to elaborate and execute a plan of action that avoids recurrence, with subsequent verification of efficacy and standardization. The obtained results met the proposed objectives and it was possible to determine that the factor generating the undesired event was the inadequate dosage of demulsifier in the treatment of the oil produced and with the standardization of the operational parameters of the process plant. There was success in eliminating the problem with the maintenance of the knowledge obtained to maintain the operation of the platform within the issues considered safe in relation to the environment, people and assets.

Keywords: Pipeline; Corrosion; MASP.

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1. INTRODUCTION

A common goal for most companies is to improve their processes and reduce waste, aiming to increase profitability through customer satisfaction. Given this global scenario, the oil industry reinforces the urgency for innovations aimed at optimizing its internal processes and a strong focus on operational safety, as recommended by the National Petroleum Agency (ANP, 2006). In this sense, this phenomenon has encouraged organizations to improve their production processes to stay in the market.

In Brazil, this offshore production still has its main knowledge base in the mature fields of the Campos Basin, which allowed the migration to the pre-salt fields in the Santos Basin. But how do you reduce waste, increase profitability and still serve customers satisfactorily? One of the outputs may be to eliminate problems.

In this sense, in order to assist companies in this difficult task, the MASP (Analysis and Problem Solving Method), based on the PDCA cycle (Plan, Do, Check, Action), presents itself as an effective methodology to achieve the objectives of the organizations. It uses the prioritization of problems in order to solve them in a definitive way. According to Campos (2014), the domain of this method is the most important in Total Quality Control theory (TQC). To do this, it uses eight steps, in addition to quality tools, for its implementation, divided according to the following order: Problem identification, Observation, Analysis, Action plan, Action, Verification, Standardization, and Conclusion.

Thus, using the Analysis and Problem Solving Methodology (MASP) as a study tool, from the development of the Plan stage of the PDCA cycle, the present work sought to detail a specific case experienced by a semi-submersible production (SS) platform, in operation in the country, which owns its pipeline that is responsible for allowing the disposal of all volume of its oil produced for another type of Floating, Production, Storage, and Offloading (FPSO) platform, with a severe corrosivity rate.

This study aimed to identify the basic causes responsible for the increased rate of corrosivity and subsequent definition of the actions necessary to block this cause. Finally, actions should be standardized to ensure that the causes that generate or contribute to the occurrence of the problem do not recur in the future. The existing methodology in MASP can and should be used to treat problems of different natures, as long as the analysis can be structured according to the data available for the study.

Among the factors that justified the importance of the proposed study, the following can be cited: High cost involved in the production stoppage of the unit of origin of the pipeline; Environmental risk that this duct represents when it does not meet the minimum safety requirements; Risk of negative impact on the image of the producer organization in the event of a leak from this pipeline; Examples experienced in the world involving oil producing companies that have generated incalculable environmental, patrimonial and financial damages.

2. THEORETICAL FRAMEWORK

2.1. Method of Analysis and Troubleshooting (*Método de Análise e Solução de Problemas* – MASP)

The methodology of analysis and solution of problems aims to treat problems that are not so structured, as the determination of an optimal production to balance the productive line, but that represent the great majority of the problems of a company. An example is the failure to manufacture a product or occurrence of deliveries made at wrong addresses (Toledo, 2010).

The application of MASP in a case study carried out in a paper industry proved to be effective, reducing losses from simple actions, without imposing costs to organize the alteration of the way of work, only with the awareness of the employees, demonstrating the need to eliminate losses in the process (Tzaskos et Gallardo, 2016).

According to Bastos Júnior (2016), MASP is an efficient method to achieve improvements, to involve employees and to improve the decision making regarding the quality of products and processes, considering that the solution of problems is reached through the analysis of the relationship between characteristics and causes of an unwanted event, taking appropriate corrective actions.

The survival of businesses in the market is conditioned on the ability to offer quality products and services at a price that the consumer is willing to pay. In this scenario, MASP allows organizations to implement the continuous improvement of their processes, aiming at quality and cost reduction (Cury et Andion, 2016).

According to Campos (2014) "A problem is the undesirable outcome of a process". Given this definition, the MASP structure is composed of eight steps as shown in Figure 1.

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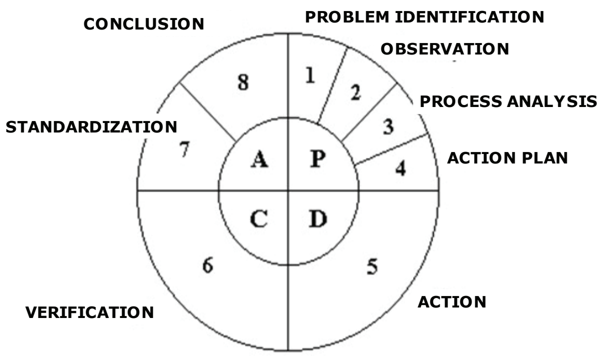

Figure 1. PDCA enhancement cycle or MASP in eight steps
Source: Campos, 2014.

These phases that make up the MASP can be summarized, according to Figure 2, in the form of a flowchart, in which Carpinetti (2012) relates the descriptions of the phases and their objectives in summary form. It is observed that in the verification phase the flowchart goes through a decision, which evaluates whether the blockage to the causes of the problem was effective. And if not, the process resumes the observation step of the problem.

2.2. Quality tools used in MASP

The MASP presents eight steps and, according to each of them, different tools are used to achieve the objectives of each phase. Table 1 lists the quality tools and their applications in the PDCA and MASP phases. It is observed that some tools are used in more than one phase of the cycle, as in the case of Brainstorming (Carpinetti, 2012).

Carpinetti (2012) defines that some of these tools are classified as "The seven quality tools", they are: Stratification; Check sheet; Pareto diagram; Cause and Effect Diagram; Histogram; Scatter diagram; and Control chart.

Others, such as "The seven management tools": Relationship diagram; Affinity diagram; Tree diagram; Prioritization matrix; Matrix of relations; Process Decision Program Chart; Activity diagram (arrow diagram). And in addition to these, there are some very widespread, which are: 5S; Process mapping; and 5W1H.

3. METHODOLOGY

PDCA	Flowchart	PHASE	OBJECTIVE
P	1	Problem identification	Clearly define the problem and recognize its importance
	2	Observation	Investigate the specific characteristics of the problem with a broad view and from various points of view
	3	Analysis	Discover the root causes
	4	Action plan	Design a plan to block root causes
D	5	Action	Block root causes
C	6	Verification	Verify that the block was effective
	? (N → 2; S → 7)	(Was the blocking effective?)	
A	7	Standardization	Prevent recurrence of the problem
	8	Conclusion	Recap the whole process of solving the problem for future work

Figure 2. Troubleshooting Method – "QC Story"
Source: Carpinetti, 2012.

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Table 1. Main Purposes of Quality Tools

PDCA	MASP	Purpose	Tool
P	Identification; Observation	Identification and prioritization of problems	Sampling and stratification
			Check Sheet
			Histogram, measures of location and variance
			Pareto's chart
			Trend graph, control chart
			Process Mapping
			Brainstorming
			Prioritization Matrix
			Stratification
			Fishbone diagram
			Affinity diagram
			Relationship diagram
			Report of the three generations (past, present, future)
D	Action plan; Action	Development and implementation of solutions	Tree diagram
			Decision Process Diagram
			5W1H /
C A	Verification; Standardization; Conclusion	Verification of results	Sampling and stratification
			Check Sheet
			Histogram, measures of location and variance
			Pareto's chart
			Trend graph, control chart

Source: Carpinetti, 2012

3.1. Process description

The process involved the analysis of an underwater pipeline interconnecting two oil production units. This pipeline underwent frequent analyzes aimed at assessing aspects related to its mechanical and structural integrity. Within these tests, there were deviations that generated the need for actions to correct the problem before reaching a point that made the business unfeasible, which is the production of oil following the standards of the petroleum industry, with regard to process safety.

In view of this scenario, the necessary steps were taken to address the problem in the light of the Analysis and Problem Solving Methodology, as described below.

3.2. Stages of research

Given the characteristics of the problem that was analyzed, a large part of the activities that were part of the study had to happen "in loco", in the platform where the pipeline originates and in the one that finishes it, with complement in laboratories in onshore environment.

Thus, in order to reach the objectives delimited for this article, it was estimated that it should follow the following basic steps, as follows:

- Conduct survey of pipeline history, including operating time, construction characteristics, maintenance and operating conditions, such as temperature, pressure, and drained fluid;
- To collect the produced oil that is drained through the duct and perform laboratory tests that may indicate possible corrosion-generating agents, such as CO2, oxygen, besides characterizing viscosity, salinity, sand content and basic and sediments in water (BSW), which is the percentage of water produced in conjunction with the oil;
- To carry out a survey of the process variables that acts in the treatment of oil produced in the platform, such as pressure, temperature and separation flow, seeking to identify behaviors in disagreement with the original design that may contribute to corrosivity;
- Analyze chemicals used in petroleum processing to identify possible contributing agents to the problem;
- Evaluate the export pumps, seeking to identify limitations that may contribute to the unwanted agent.

And, based on these analyzes, define the next steps from the probable causes identified; test the hypotheses raised as

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probable cause of the event studied; when confirming the identification of the cause, develop standards so that it is eliminated or mitigated in order to allow the operation of the pipeline at acceptable levels of corrosivity; and, finally, to implement the proposed actions and verify the effectiveness to complete the work.

4. CASE STUDY

The proposed work was carried out on a semi-submersible (SS) platform of an oil-producing organization located in the Campos Basin. The unit had a daily production capacity of 100,000 barrels of oil and 3,200,000 cubic meters of gas. Being a platform that did not have water/oil separation and because it did not have storage tanks, all its production was drained by an underwater pipeline to a platform of the type FPSO.

At the time of the study, the SS had a production of 50,000 barrels of oil and 2,000,000 cubic meters of gas. This apparent idleness of the productive capacity is due to the existing volume of water from the formation associated to the oil collected, which competes with the oil at the available flow limit in the pipelines. During the study, this volume of water was in the order of 60%.

These specific features of the platform were analyzed in order to identify the possible causes that generated the severe corrosivity rate in the export pipeline, which was the reason for this work. Figure 3, below, shows the monitoring chart of this controlled variable and denotes the criticality generated by this fact for the organization.

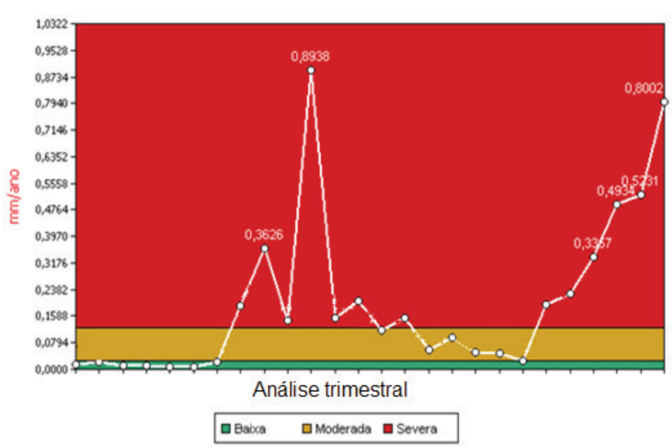

Figure 3. Pipeline corrosivity in mm/year

Source: Research Data, 2016.

Legend: Quarterly analysis; low (green), moderate (yellow), severe (red).

For the correct identification of causes and relationships between them, it was necessary the participation of a multidisciplinary team, given the amount of subjects involved in the investigation to treat the problem. It was hoped that, using some of the quality tools, especially following the methodology recommended in the MASP, to achieve the general and specific objectives of the current study. As described in the methodology, the previously defined steps were followed (see section 3.2), in agreement with the phases that make up the Methodology of Analysis and Problem Solving, which will be presented below.

4.1. Identification of the problem

The identification phase of the problem was characterized by meetings designed to allow the integration of several company actors involved in the problem and to collect as much information as possible so that the undesired fact was clearly defined. Thus, brainstorming sessions that will not be described in detail in the work due to the several propositions raised were performed.

Other quality tools used in this step were the stratification and the check sheet that allowed access to the information contained in Table 2, referring to the characteristics of the pipeline to guarantee success in the identification phase of the problem.

The pipeline under analysis had the constructive characteristics cited in Table 2 and was followed by a pig run routine (a cylindrical or spherical device designed and used for the purpose of cleaning the interior of ducts) weekly between the platforms of origin and destination. It is noticed that its length surpassed 9 kilometers.

Table 2. Constructive characteristics of the pipeline

Stretch	Length	Diameter	Feature
A	826 meters	14,5”	*Flow line*
B	6616 meters	16”	*Riser*
C	2530 meters	16”	*Riser*
D	689 meters	14,5”	*Flow line*

Source: Research Data, 2016

In addition, it had design temperature and pressure compatible with those practiced during the operation of the duct, according to a survey carried out with the historical data, thus not showing that there may have been inadequate working conditions that would generate fatigue in it.

Chart 1 presents the sequence of questions that were asked during this phase of MASP development, as described in the literature review. Based on these statements, it was possible to continue the study and reach the next stage, which will be detailed in the next topic.

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Chart 1. Steps used to identify the problem

PROBLEM: SEVERE CORROSIVITY IN THE OIL.	
Questions	**Answers**
Is the goal well defined?	Yes, it is based on specific literature in the field of corrosion control and there are internal company standards that define these parameters.
Are there data that support the study of the benefits to the company with the solution of the problem?	Yes, the company's policies for Safety and Environment Management are in full agreement with the need to solve the problem.
Is the data reliable?	Yes, because in addition to the corrosion coupon measurement data, performed quarterly, electrical probe data are collected to prove the high corrosivity rate.
Is it worth investing in achieving the goal?	Yes, because it is a parameter that demonstrates safety for the operation of pipelines.
Is the problem focused?	Yes. Accurate corrosivity rate in the pipeline linking SS and FPSO under study.
RESULT: START PROBLEM OBSERVATION.	

Source: Research Data, 2016

4.2. Observation of the problem

This period was marked by the beginning of the deepening of the studies to know the problem. Given the specificities of the offshore environment, it was necessary to collect data on board the two platforms involved in the project, as well as conduct laboratory tests to characterize the fluid drained in this pipeline. This information was relevant to continue the analysis, allowing the evolution to the next phase, solution of the problem.

The problem that was proposed to deal with was the corrosivity of the pipeline between the SS and FPSO platforms, as already outlined in the study object. This severe rate was known from the data acquisition of mass loss coupons, commonly called corrosion coupons. There was standardization in the company regarding this collection and analysis of data of these components that allowed concluding that the pipeline in question was in a vulnerable state that could generate its rupture, which would cause a serious environmental and financial damage, besides the impacts to the company image.

As can be seen in Figure 3, the corrosivity rate presented growth, reaching a level considered severe. At the first peak there was a deficiency in the monitoring process and that measurement could be considered false and was not part of the proposed analysis. These data were collected quarterly. Periodically, in addition to this measurement, data were collected from an electrical probe that also mediates corrosivity in the pipeline. This probe confirmed the corrosion coupon data, indicating severe corrosivity.

As quality tools at this stage of the process, stratification and brainstorming sessions were also used to begin the survey of probable causes for the problem. A new flowchart was elaborated, which was simplified in the form of Chart 2, to allow proceeding to the analysis phase of the problem.

Chart 2. Steps used to observe the problem.

AFTER THE PROBLEM IDENTIFICATION PHASE	
Questions	Answers
Is it possible to look at the problem from various angles?	Yes, the corrosivity rate was identified from mass loss coupon measurement and confirmed by means of corrosive monitoring electrical probes. Its effects could be perceived from other process variables.
Does the data represent the situation and are they accurate?	Yes, same as the previous answer.
Divide the problem into simpler problems.	
Prioritize issues to be addressed	
Define specific and non-delegable goals.	
RESULT: START PROBLEM ANALYSIS	

Source: Research Data, 2016

From Table 2, it can be defined that the simplest problems that can be listed from the corrosivity rate were related to two possible causes raised in the brainstorming discussions. They are: the contribution of some well for the generation of a corrosive process for the pipeline or the process characteristics that generate free water in the pipeline. Thus, these two possibilities were treated as will be detailed below in the analysis stage of the problem.

4.3. Analysis of the problem

At this stage of the analysis it is necessary to know the process and identify the related causes, so that the proposals are as close as possible to the root cause of the object being studied. From this stage, the hypotheses should be tested in order to discard the rejected ones and going deeper into those that remain valid.

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Table 3. Check Sheet: Blend Composition.

WELL	OIL FLOW (m3/d)	BSW (%)	FLUID FLOW (m3/d)	WATER FLOW (m3/d)	TOTAL LIQUID %
1	305	69,3	993	688	5,73
2	65	84,0	406	341	2,34
3	265	47,7	507	242	2,92
4	290	60,0	725	435	4,18
5	370	68,0	1156	786	6,67
6	275	78,4	1273	998	7,34
7	470	70,3	1582	1112	9,13
8	530	72,0	1893	1363	10,92
9	1090	3,5	1130	40	6,51
10	490	72,0	1750	1260	10,09
11	245	79,2	1178	933	6,79
12	290	38,0	468	178	2,70
TOTAL SATEL-LITES	4685	64,1	13061	8376	75,33
13	80	89,0	727	647	4,19
14	230	49,0	451	221	2,60
15	165	85,7	1154	989	6,65
16	80	1,3	81	1	0,47
TOTAL MSP-1	555	77,0	2413	1858	13,92
17	620	40,0	1033	413	5,96
18	485	41.6	830	345	4,79
TOTAL MSP-2	1105	40,7	1864	759	10,75
OVERALL TOTAL	6345	63,4	17338	10993	100,00

Source: Research Data, 2016.

Petroleum was collected from the production wells on the SS platform and Table 3 was generated, which brings the blend composition of all wells generated by all the satellite wells and underwater production manifolds (MSP). It was ruled out the possibility of some individual well or the wells of some reservoir that contribute to the generation of this corrosivity, since the laboratory tests allowed verifying that there was no significant difference between the emulsions of the wells and of the blend, as well as there was not a considerable alteration of these wells at times where corrosivity was mild to the time when it was severe. Thus, this hypothesis was considered less probable.

From the deepening of the hypothesis that some process characteristic is contributing to the generation of the undesired event in the pipeline, a fault tree was elaborated described in Figure 4.

In view of this fault tree, presented in Figure 4, two paths were delineated to be detailed in search for the root cause: the project deficiency of the de-emulsifying injection pumps and the difficulty in the process of the flow of the produced oil.

The hypothesis that the demulsifier dosing pump was not able to operate at lower flow rates than usual is not proven, because when performing field tests, it was possible to operate with lower flow rates. The evidence demystified this hypothesis, which until then was one of the probable ones pointed out by the field personnel who operated the process plant.

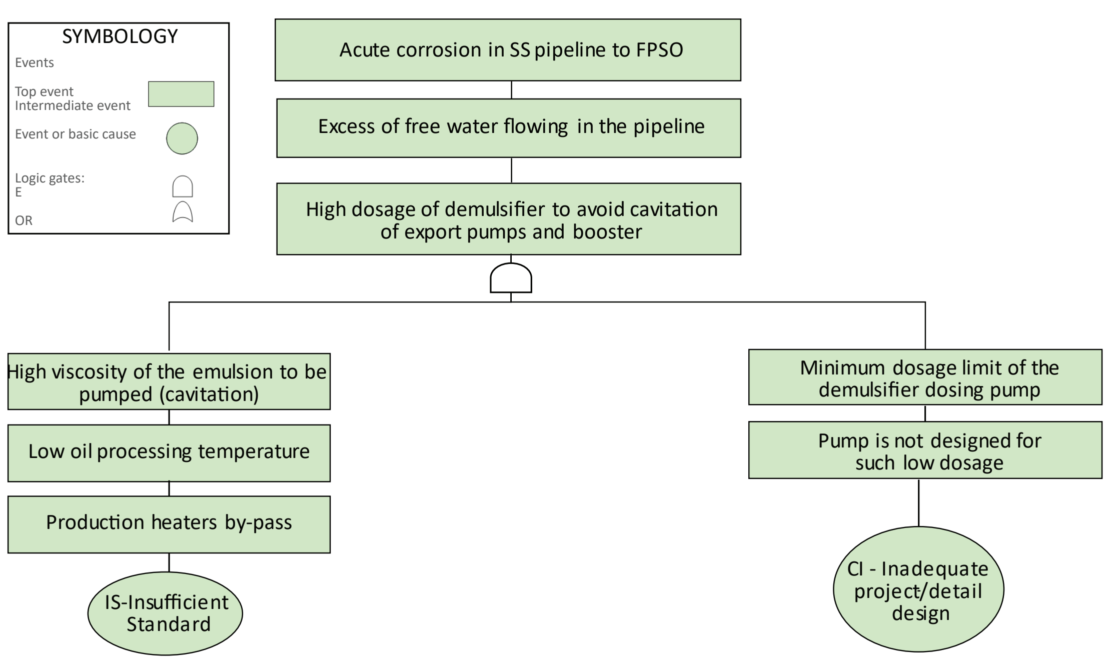

Figure 4. Failure tree of identified hypotheses

Source: Research Data, 2016.

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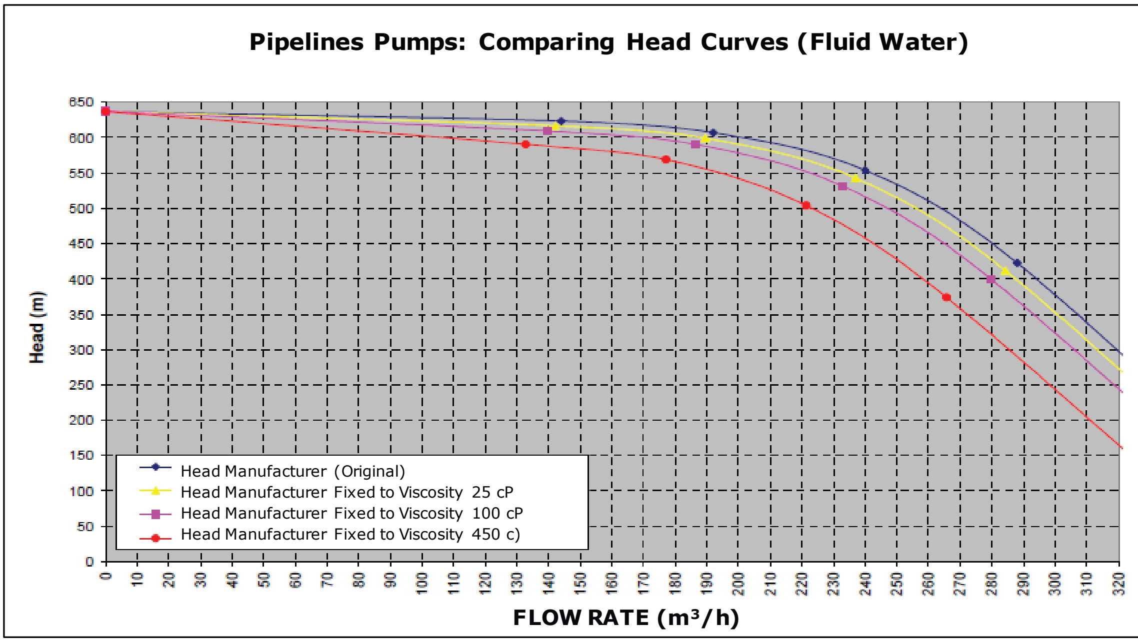

Figure 5. Curve of heads of export pumps

Source: Research Data, 2016.

Thus, it remained to deepen the studies in the other line of reasoning that pointed to the generation of free water due to the injection of demulsifier, which, therefore, was due to a difficulty of flow that generated cavitation of the export pumps.

Therefore, a survey was made on the head (flow capacity) of the export pumps, in order to compare it with the project of these pumps (Figure 5) and, thus, to confront these data to draw conclusions.

In addition, the flow of oil from the pipeline was characterized, the blend generated by the wells. These characteristics are found in Tables 4, 5, 6 and 7, which will be explained below in conjunction with the graph of Figure 5.

Table 4. Characterization of the blend

Test	Blend	(output)	(input)
Emulsified water in petroleum (% w/w)	59,2	0,74	0,2
Specific mass (g/cm³)	0,995	0,8826	0,8842
°API	10,2	28,1	27,8
Presence of free water in the bottle	No	Yes	Yes

Source: Research Data, 2016.

Table 5. Rheology of the blend prepared in the laboratory (Final water content of 59.2% w/w).

Temp (°C)	Viscosity (mPa.s)				
	20 s-1	50 s-1	80 s-1	120 s-1	250 s-1
60,00	195,60	176,70	167,70	160,40	147,80
50,00	248,50	225,30	214,20	205,10	189,60
40,00	336,90	307,10	292,90	281,20	261,10
30,00	500,30	450,80	427,40	408,10	375,50
20,00	871,00	758,70	706,80	664,90	595,30
15,00	1442,70	1176,80	1060,00	968,60	822,70
12,00	1805,90	1454,60	1301,80	1183,00	994,80
8,00	2644,60	2037,50	1782,40	1588,10	1288,70
4,00	3666,30	2755,20	2379,60	2097,00	1668,10

Source: Research Data, 2016.

A blend was generated in the laboratory with the contribution percentage of each well, according to Table 3. With this blend in hand, tests were carried out to gauge the viscosity that this emulsion generated and it was concluded that, without the injection of demulsifier, this fluid had 450 cP, according to Table 5.

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Table 6. Rheology of the blend at the SS outlet (Final water content of 0.74% w/w)

Temp (°C)	Viscosity (mPa.s)				
	20 s-1	50 s-1	80 s-1	120 s-1	250 s-1
60,00	8,20	8,00	7,90	7,80	7,60
50,00	13,70	13,50	13,30	13,20	13,00
40,00	20,90	20,50	20,40	20,20	19,90
30,00	32,30	31,90	31,70	31,60	31,30
20,00	57,80	57,00	56,60	56,20	55,60
15,00	117,20	113,40	111,50	109,90	107,10
12,00	186,70	174,00	167,80	162,70	153,80
8,00	366,10	306,60	280,00	258,80	224,50
4,00	600,40	473,80	419,60	377,90	312,60

Source: Research Data, 2016.

Table 7. Rheology of the blend at the arrival of FPSO (Final water content of 0.20% w/w)

Temp (°C)	Viscosity (mPa.s)				
	20 s-1	50 s-1	80 s-1	120 s-1	250 s-1
60,00	9,20	8,80	8,50	8,30	8,00
50,00	13,50	12,80	12,50	12,30	11,80
40,00	19,60	18,90	18,50	18,20	17,70
30,00	30,40	29,90	29,70	29,50	29,10
20,00	55,30	54,70	54,40	54,10	53,70
15,00	120,00	114,80	112,30	110,10	106,30
12,00	196,40	180,10	172,30	165,80	154,70
8,00	383,50	316,70	287,10	263,80	226,30
4,00	625,60	486,50	427,60	382,60	312,80

Source: Research Data, 2016.

Another relevant factor is presented in Table 4, where it was found that the injection of demulsifier in the SS platform blend promoted the almost total separation of the emulsified water, with the result that the fluid at the outlet has emulsified water content of less than 1%. Thus, Tables 5, 6 and 7 demonstrate that the demulsifier injected in the SS promoted viscosity reduction from 450 cP to 30 cP.

Figure 5 shows the heads' graph of the pipelines for the viscosities of 25 cP and 450 cP. As can be seen from the analysis of this figure, there was loss of 50 m head at the operating flow of 182 m³/h (operation flow at the time of the study), when the fluid pumped was the SS blend, proving the need for the reduction of the viscosity of the fluid to be drained to the FPSO. Considering the output curve (25 cP), at the same operating flow, it can be observed that it was closer to the head of the manufacturer than the blend *in natura*.

Thus, the next step was the hypothesis test, because until that moment, it was possible to conclude that the corrosivity was caused by excess free water in the duct, which was therefore caused by the demulsifier dosage, which is a necessary chemical product, given the high viscosity emulsion generated in the blend and the flowability of the export pumps.

However, one question that comes at this moment is: why did not this problem happen a few months earlier? In contact with the operation technicians of the platform, it was informed that the injection of demulsifier has not happened for years, and that, with the increase of the BSW of the wells, the emulsion generated by the petroleum produced began to present serious difficulties of flow, when there was the idea of injecting the demulsifier, which was in disuse until then. This opinion was carried forward, which generated stabilization in the flow, promoted reduction of viscosity and eliminated the cavitation of the export pumps.

However, as analyzed so far, this success in the flow generated side effects for the pipeline, which now has a severe corrosivity rate. It was necessary to test this hypothesis and to evaluate whether the conclusion needed to cope with this problem would be obtained, since the demulsifier became an essential chemical, given the difficulty of flow that existed without its performance.

4.4 Action Plan and Action

Due to the results obtained, it was necessary to go to the field and find a balance point that would meet the limitation of flow from the viscous emulsion that was produced in the blend of the SS platform and that generated the least free water possible, in order to protect the duct of severe corrosivity to which it was exposed.

A 5W1H matrix, which defined the actors and their participation in the hypothesis test and search for a solution to the problem, was elaborated. Due to the confidentiality of the company's data, this matrix will be omitted; however, in general, the actions taken will be clarified as follows.

It was started from the injection point of demulsifier at 20 ppm as the platform operated and process temperature at 38°C. With this initial condition, practically 100% of the emulsified water was generated in free water form and the pumps did not present flow difficulty.

Thus, an increase in the process temperature and reduction of the demulsifier dosage was gradually performed. Each point that was reached was maintained for at least 6 hours of operation until it reached a new level. And in each phase, the collection of the blend produced for the measurement of free water in the pipeline was carried out.

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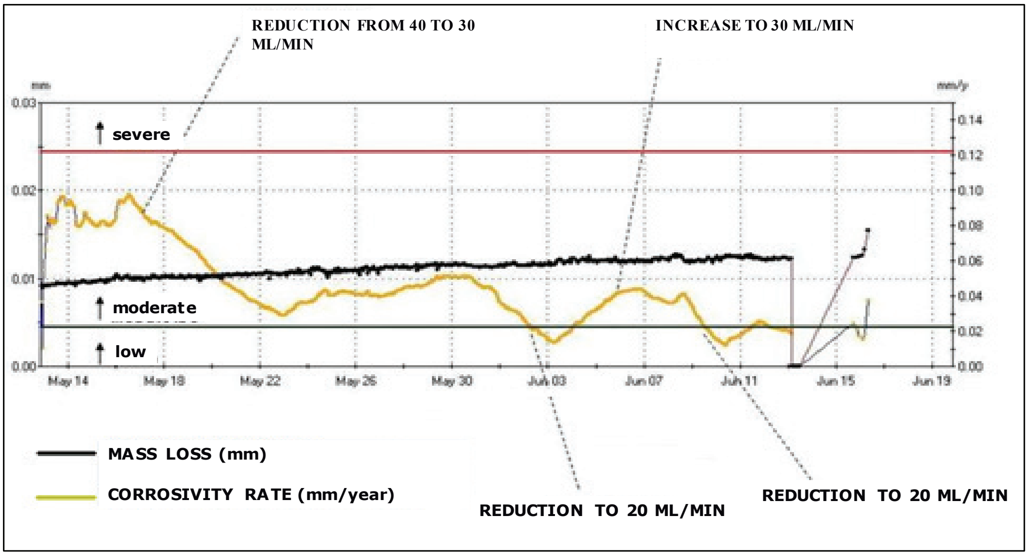

Figure 6. Reduction of pipeline corrosivity rate during the test.

Source: Research Data, 2016.

This led to a separation temperature limit of 54ºC and a 4 ppm de-emulsifier dosage. This level of optimization generated a blend with 90% of emulsified water. From this optimum point, the data collection of the electrical resistivity probe that affects the rate of corrosivity of the duct was performed. And it showed a gradual decrease during the test, until in obtaining the best point between flow and free water, a rate considered light, thus proving that the cause of the problem was the dosage of demulsifier, which generated almost 100% free water and, contributing to this injected ppm requirement, the process temperature remained below capacity

Figure 6 shows the data control chart of the electrical pipeline corrosion measurement probe which proves that, before the test was attempted to reduce the dosage of demulsifier, the rate was close to severe and when an optimum flow point was reached, the process temperature and generation of free water reached corrosive levels considered light. Therefore, the cause of the problem was proven and a threshold of process parameters that eliminated the problem was obtained. At this point, it is no longer possible to proceed to the phase of standardization and completion of MASP.

The control graph of Figure 6 can be complemented by the dispersion diagram of Figure 7, which proves the direct relationship between the dosage of demulsifier and the percentage of free water in the duct, thus generating an increase in the rate of corrosivity. Therefore, increasing the dosage of the chemical promotes the increase of the unwanted rate in the pipeline.

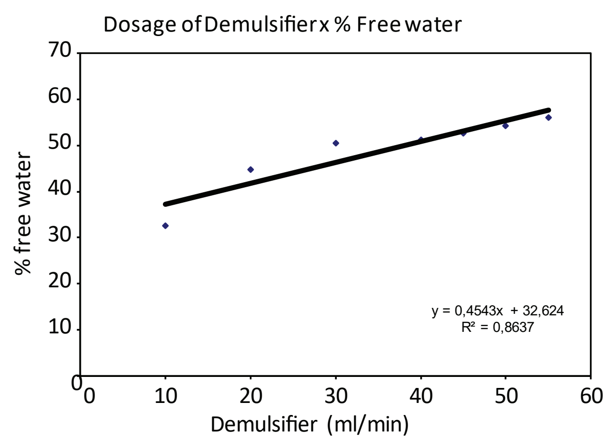

Figure 7. Scatter plot. Dosing of demulsifier x% of free water.

Source: Research Data, 2016.

4.5 Verification, Standardization and Conclusion

In this final phase, the information obtained in the previous steps was recorded, allowing a rich documentation, which allows basing the definitions that will be given as a way to standardize the actions in the company. The company in analysis has a collection of Information Technology that allows a standard to be registered in a specific system and it is accessible to all stakeholders and that they are trained in this procedure, generating evidence of such training.

Thus, due to the results achieved, the standardization necessary to allow the perpetuation of actions, so that the pro-

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blem does not occur again, was summarized to the following control points of the process plant that were inserted in the operation manual of the platform:

- Separation temperature: 50°C to 55°C.
- Dosing of demulsifier: 4 ppm.
- Monitoring of free water in the pipeline: Daily analysis by means of collection of exported oil, aiming to guarantee the control of the effectiveness of the process variables to reduce corrosivity.
- Corrosion monitoring: Corrosion measurement point created online.

With the implementation of these proposed actions in the form of a procedure, it was observed the maintenance of the corrosivity rate within the limits considered light, thus confirming that the methodology of analysis and solution of problems was efficient, reaching the proposed objectives.

With this standardization, the organization was able to dedicate itself to other decisions that became more important, because this problem was under the control of this work. The risk was minimized and blocking actions were effective to maintain the operational safety of the platforms involved.

The work done showed that theory and practice must always be united, for without the intensification of research in the field, any conclusion that was generated would be very superficial. And, in this way, some papers that served as a framework for literature review could have their conclusions compared to an adequate discussion.

Thus, Lima (2010) concludes his project about the use of pigs to maintain the integrity of ducts citing that among the possible causes for the generation of high corrosivity rates is the use of chemicals that have acidic characteristics such as the biocide. Complementing this conclusion, it can be observed that the demulsifier is also a potential generator of high rates of corrosivity in the pipelines, due to the release of free water that may occur and the characteristics of this oil, mainly of its BSW and blend viscosity formed.

Another important study that served as input for this work was the article by Mainier et Silva (2004), which dealt with the formulation of corrosion inhibitors and their interfaces with the environment. It has also brought to the conclusion the importance of environmental awareness that should guide companies in the sense of not designing products that meet socially and environmentally responsible policies. This proposal is very close to what was sought from the beginning of this project, to identify the root cause of the problem and to treat it properly, as it could be very convenient for the management of the company to simply adopt the action of increasing its process plant with the injection of a new chemical, a corrosion inhibitor, without even seeking the motives of that chemical process happening.

E Toledo (2010), in his tutorial on the steps to use the MASP tool, makes it clear that strictly following all the steps that make up the methodology is the secret to the success of its implementation, since, once this sequence becomes clearly understood, the process improvement activities will be logically and cumulatively consistent over time. In the present work it was possible to arrive at the same conclusions, since the discipline in the use of the method allowed reaching the objectives proposed at the beginning of the project. Thus, it is necessary to trust the tool in order to get the best results possible. And this quality in the processes is something that does not come to an end. It is an ongoing process, as recommended by total quality management, and the PDCA must always be up and running.

5. CONCLUSION

During the execution of the study, it took a lot of persistence to remain on the way to seek the root cause of the problem, since much information obtained was divergent or proved in the development of the study that had no basis to be taken as truth, that is, they are the so-called myths that are generated and which, for a good period, are regarded as justifications for certain phenomena. It was necessary to obtain technical explanations, proven, for each phase of the process, to reach an understanding of the problem and follow the phases of the MASP tool.

An important conclusion that should be emphasized was the need to integrate a multidisciplinary team to address the proposed problem. The success of this study is due to the cohesion existing between different managements, which have different interests in this process, but which were imbued with the same objective: to discover the cause of the severe corrosivity rate in the pipeline between the SS and FPSO platforms and to treat it, so that it does not recur.

Corrosion is a phenomenon that has a number of factors that contribute to its existence, making it a complex problem to be addressed. It is known that the offshore environment is aggressive and a large part of the causes of corrosion is associated with this medium. However, in the study carried out, the undesired event did not occur in the external environment, but in the transfer pipeline between two platforms, that is, questions related to the production process should guide actions for a solution to be reached.

One challenge that had to be overcome was to carry out field tests, and it was necessary to break a series of para-

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digms of the operation team, which believed in certain premises. As for example, the process temperature, operating at about 38°C, with the by-pass of the heat exchangers that heat the oil by more than 50% aperture, that is, it does not use all the thermal load available to heat the oil. However, with the tests, it was possible to prove that this procedure was inadequate.

And as a point of attention, it is important to emphasize the importance that must be given to engineering studies of processing, among them the engineering of elevation and drainage, maintenance of surface facilities and petroleum engineering as a whole, to guarantee the conditions of operability within the regulatory requirements both internal to the company and the regulatory bodies. These disciplines are intrinsically related, one interferes in the other and one collaborates with the other. Thus, the integrated environment for these disciplines is a process management model that has much to offer for the development of the potentialities aimed by the oil industry.

In general terms, the work reached the proposed objectives, and the results obtained were of great relevance for the oil transportation process through the pipelines, since the company managed to keep the process under control and means were created to perpetuate these actions. That is, the PDCA was rotated in all its phases, as recommended by the MASP.

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