Implementing Process Safety In a Petrochemical Complex – 25 Years of History In Camacari, Brazil

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1. INTRODUCTION

Camaçari Petrochemical Complex started its operation in 1978, with the construction of a basic petrochemical unit and a fertilizers unit. Over the years, it has increased the number of sites installed to 90, being 63 chemical and petrochemical, with a capacity installed of over 11,5 million ton/year, 15 thousand direct employees and 20 thousand employees thought subcontractors. The major features currently presented by the Complex are industrial expansion and diversification.

Today, the largest integrated industrial complex in the southern hemisphere, most of the Complex companies is connected through a piping network to a raw material unit. The largest company of the Camaçari Industrial Complex and one of the five major private enterprises of the country, BRASKEM raw material unit receives petroleum-by-products from PETROBRAS, mainly naphtha, and processes them into primary petrochemicals (ethylene, propylene, benzene, toluene, butadiene, xylene, solvents and others).

All these products plus utilities such as electric power, steam and instrument air are supplied from a central production facility and to the neighboring second generation industries, for manufacturing intermediate and some final petrochemicals, as represented in Figure 1.

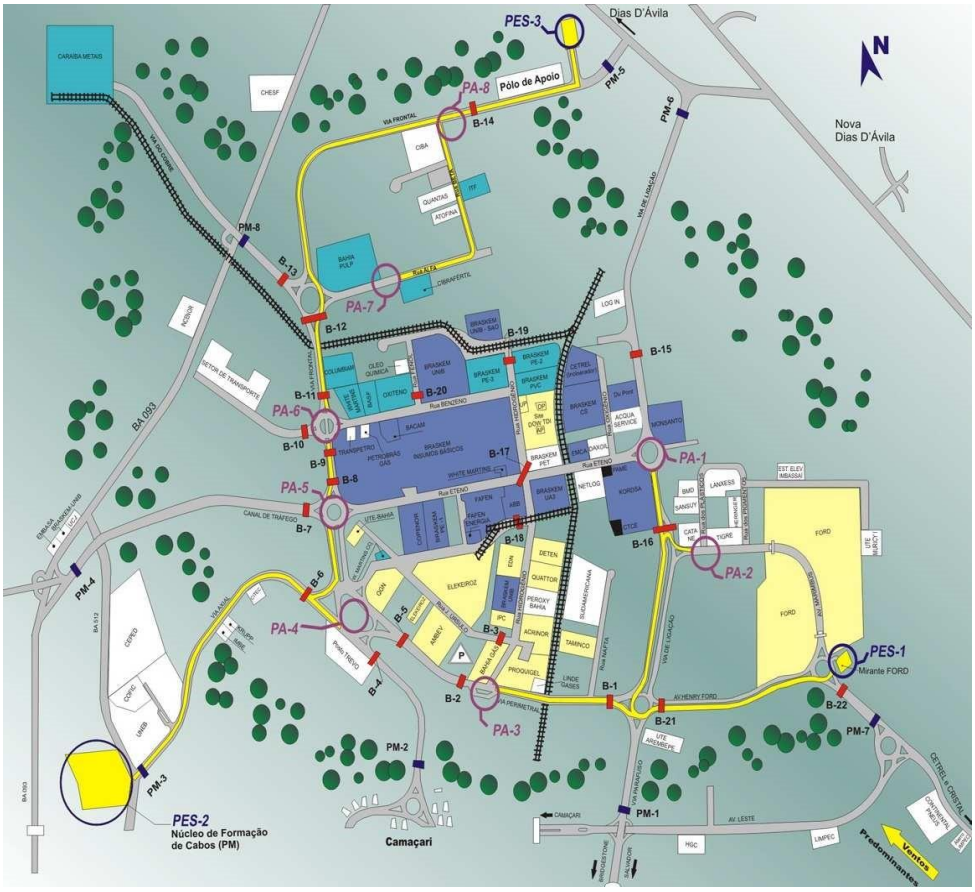

Figure 1: Camaçari Complex

By the end of the 80's an expansion of Camaçari Complex was planned and to accomplish with the environmental law established on the State of Bahia, an Environmental Impact Assessment was performed. This study indicated the need to evaluate the risks of operation of the complex towards the nearby community. With that, the first initiative on Process Safety was established in Camaçari.

To coordinate the activities with all companies and decide how to develop the studies, COFIC – Camaçari Industrial Development Committee1, established a Technical Steering Committee with participation of professionals from different companies to define methodology, criteria and how to conduct the study, named APPOLO 1.

Over the years, COFIC has promoted several initiatives towards excellence in Safety in Camaçari Complex (including Process Safety and Non-Process Safety) that today has a performance superior of the national average in Brazil and compared to good practices around the word.

This paper presents the evolution of the implantation of Process Safety, starting with fulfillment of mandatory requirements to a sustainable position, over 20 years of work.

2. THE PROCESS – PAST AND PRESENCE

2.1. Over the Years

The process of implementing a Process Safety Culture in Camaçari Complex started in 1990, after the identified need of an assessment of the risks that the activities of the companies towards the nearby communities. The main milestones of this process are indicated below.

1990	First Requirement of Risk Assessment
1991	Development of Technical Specification for APPOLO 1
1992 to 1995	APPOLO 1 Project
1996	First NUDEC - Community Development Center
1997	Development of Award on HSE
1998	First Award on HSE; First Emergency Drill
1999	
2000	Development of Technical Specification for APPOLO 2
2001 to 2004	APPOLO 2 Project
2005	Initiated Risk Management Program Development and Implementation
2006	First Emergency Drill with Communities; Pipelines on RMP
2007	Road Transportation included on the RMP
2008	
2009	New Regulation for Risk Management for the State of Bahia
2010 to 2016	Continuous implementation of RMP
2017	Review of Regulation for Risk Management for the State of Bahia

COFIC was created with the mission to promote the development of the complex. It centralizes the administration of common areas in the complex, relationship with govern agencies and communities

The next sections describe the main steps of the process that Camaçari has gone thorough over the years, since 1990, telling the history until the present situation.

2.2. APPOLO 1 Project

As previous indicated, to guarantee the operational license for the expansion of Camaçari Complex, it was requested by the Environmental Agency from State of Bahia the development of a risk analysis study for the associated companies.

This was one of the first formal requests of risk assessments for chemical and petrochemical companies in Brazil. A total of 31 companies were involved and the study was conducted by PRINCIPIA (consulting company acquired by Det Norske Veritas – DNV in 2000). The methodology used on the study was the Preliminary Hazard Analysis (PHA) and a risk matrix was used to classified severity, likelihood and risk. During the analysis around 9.000 scenarios were identified and classified, with focus on impact to people. The risk matrix was divided in to regions:

- Acceptable risk: no mitigation needed
- Mandatory mitigation: recommendations mandatory to reduce the risk.

Note that ALARP (As Low As Reasonable Possible) approach was not used on this study. From the identified scenarios, around 1% was classified on the region with mandatory mitigation, with 93 recommendations. For the remaining scenarios, around 1,500 suggestions, without mandatory implementation were identified, but also for safety and continuous improvement.

The scenarios with potential to reach the nearby communities were subject to consequence analysis. No quantitative risk assessments were performed during APPOLO 1 Project.

The limited experience of the professionals involved on the study, the lack of similar studies in the country and possible misunderstanding of the results towards the communities and inside companies themselves were some of the difficulties to be transposed during the four years of the project [1]. At that time, no effort was given or established in following the implementation of the recommendations and suggestions as well continuing the risk analysis and risk management on a more structured and centralized condition on Camaçari Complex.

APPOLO 1 was the first step towards process safety and after this first initiative several other have followed.

2.3. Polo Award on Health, Safety and Environment

In 1997, the Polo Award on Health, Safety and Environment (HSE) was created to encourage improved performance among the COFIC-associated companies in prevention of accidents, also promoting the exchange of experience in Health, Safety and Environment in the Complex.

It is a volunteer process, where associated companies can candidate themselves for the award. A team composed of 80 auditors assess above 1000 items addressing the three areas of the award (Health, Safety and Environment) as well as the corresponding evidences of performance. Other associated companies that do not wish to participate on the award are still audit during that year. Audit results are transformed into recommendations for the companies [2].

The protocol for the audit process, first created in 1997 and applied in 1998, has passed through reviews and has now 16 elements, reinforced in 2007 with more complex requirements on Process Safety and Risk Analysis, including Leadership and Administration, Competence and Training, Planned Inspections in HSE, Analysis and Statistics in Incidents and Accidents, Emergency Control, Company Procedures, HSE Audit, Personnel Protection Equipment, Occupational Hygiene, Risk Management and Process Safety, Communication, Workplace Safety Management, Occupational Health, Subcontractors, Environmental Management and Safety on Road Transportation (Products and Waste).

To guarantee the classification and the award, a criterion based on rate of accidents with loss of time and level

of compliance on the protocol is established. To obtain the highest classification, the company must [2]:

Classification				
Category	Number of items to be audited	4 stars	5 stars	Excellence in HSE
Bronze	41% of total	- 70 to 85% of points	- > 85% of points	-
Silver	61% of total	- 85% of points	> 85% of points	-
Gold	100% of total	- 80% of points	- 90% of points	- above 90% of points

Over the 20 years of the award, an increase of the compliance with the protocol has been achieved by the companies and from the first year with the competing companies with 4 stars to the last years with companies achieving the level of Excellence, demonstrates that an upgrade on performance can be obtained throughout implementation of a management system.

Results from 2016 indicate a total of 6 companies has achieved the Excellence category.

Table 1. Evolution of the Award on HSE [2]

Year	Protocol Elements	Companies Participating	Awarded Companies				Average of Compliance (%)
			4	5	Excellence	Total	
1998	12	10	10	-		10	76,3
1999	14	10	9	1		10	78,8
2000	14	15	12	3		15	80,5
2001	15	18	9	9		18	86,3
2002	15	22	11	11		22	86,1
2003	15	19	5	14		19	88,5
2004/2005	16	16	-	16		15	83,4
2006	16	18	4	5	3	18	84,4
2007/2008	16	18	3	9	3	18	82,9
2010	16	19	4	2	4	16	84,7
2012	19	20	3	11	4	18	88,8
2014	19	22	5	9	4	18	89,0
2016	19	22	2	10	6	19	90,1

The award has a large contribution to exchange experiences and best practices in HSE between companies and their professionals. It mobilizes all areas the company and its workforce on establishing the evidences, with consequent engagement in preventive measures, making work safer environment. Significant improvements, in 2016, occurred in ergonomic area, occupational hygiene, process safety, occupational health management and environment. It also highlights the commitment of the leaders of the companies on the adoption of preventive measures [3].

The Award Polo HSE was established by COFIC to stimulate the exchange of experiences between the enterprise and foster improved security management, health and the environment, and contribute to the reduction of accidents and consolidate the position of the Polo as an environmentally safe complex. More than a prize, it is an effective verification system of good security practices, health and environmental protection and exchange of experience between the companies associated with the COFIC as well as its contractors.

2.4. APPOLO 2 Project

In 2000, to obtain a new environmental and operational license for the Complex, a review of the risk analysis performed from 1992 to 1995 (APPOLO 1 Project) was requested by the State of Bahia Environmental Agency.

The Technical Steering Committee from COFIC created a new Technical Specification for the studies to be conducted, including this second time more focus on quantitative studies and new criteria for classification of risks.

The study was conducted by DNV from 2001 to 2004, including companies in the following main sectors: chemicals, petrochemicals, beverage, cupper and automobilist. The transportation of dangerous goods by pipelines, railway and roads, between the physical limits of the complex, was also included in the analysis.

Representatives of the main companies in the complex, with large experience in process safety, as Braskem, Deten, Petrobras, Du Pont, Monsanto and Dow have participated in the committee and elaborated a technical specification to be followed in the analysis. This specification is based on Brazilian regulations, establish by the States of Rio de Janeiro and São Paulo, and international regulations from OSHA, EPA, the Council of the European Union (Seveso II) and International Labor Organization (ILO 174).

As established in the technical specification, APPOLO 2 Project was structured in four phases [4]. The revision of the risk assessment performed from 1992 to 1996 was much more structured and a detailed methodology was developed.

- Phase 1: Preliminary Hazard Analysis (PHA)
- Phase 2: Consequence Analysis
- Phase 3: Quantitative Risk Assessment (QRA)
- Phase 4: Process Safety Management Program

PHA was again selected as the primary qualitative approach to be applied to all companies for the identification and classification of risks. A risk matrix, with five likelihood categories and four severity categories was established. The qualitative acceptability criteria for APPOLO 2 project was defined as follow:

- Acceptable Risk: scenarios classified in this category are considered in acceptable condition, not being necessary risk reduction. The measures identified for them are classified as suggestions, without obligation to be implemented.
- Global Analysis: scenarios classified in this category have as characteristics high likelihood and low consequences, the actions normally are related to inspection and maintenance activities. All measures proposed are considered Recommendations, with obligation of implementation;
- Confirm Risk: in the category, complementary studies (Consequence Analysis and Quantitative Risk Assessment) need to be performed, to confirm the risk acceptability;
- Acceptable with Consequence Analysis: for these scenarios, even though they are considered accepted, a consequence analysis needs to be performed to confirm the severity of the consequences;
- Pre-Analysis: as the category Confirm Risk, for Pre-Analysis, complementary studies are to be performed;
- Not Acceptable Risk: scenarios classified as not acceptable need to have immediate attention and the risk measures should be implemented to eliminate the hazardous condition or to reduce it to an acceptable risk.

During the assessment, over 21.000 accidental scenarios were identified, around 570 recommendations were proposed, to reduce the risk in the industry sites and transportation routes. These recommendations have the implementation status followed by the local environmental agency, per annual reports presented by COFIC. Besides that, 1,390 suggestions were identified, with the aim to increase the safety on the operations, but without obligation of implementation [5].

From Figure 2, 74% of the scenarios identified were classified as acceptable and 21% as acceptable with need to develop consequence analysis to map out the areas that could be affected by physical effects from the accidents. Around 5% of scenarios were classified in intermediate categories and were subjected to quantitative risk studies.

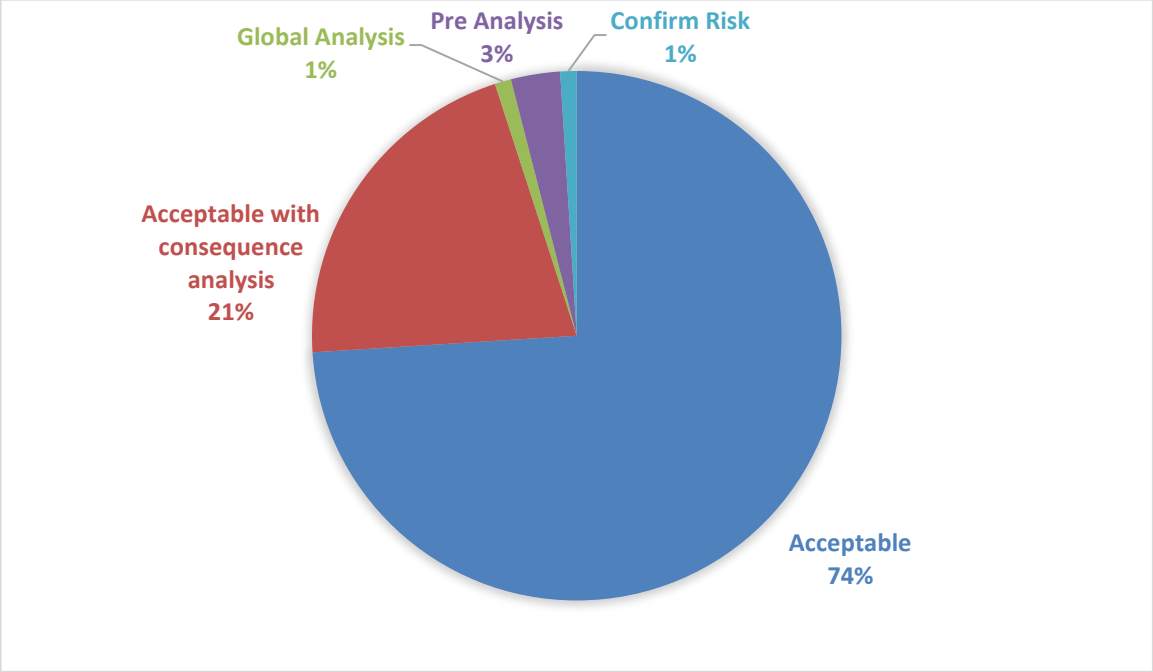

Figure 2: APPOLO 2 Risk Distribution

These results represent a significant progress comparing to APPOLO 1, especially regarding the more intense participation of the workers, number of identified scenarios and proposed recommendations and suggestions, showing that the companies saw the study as an opportunity to improve the process safety performance.

From the PHA results, all scenarios with consequences classified as critical or catastrophic were included in the Consequence Analysis. Their effects were quantified, using the software PHAST – Process Hazard Analysis Software Tool, developed by DNV GL Software [6].

A total of 1,100 simulations were developed, including process units, storage and transportation, the distribution of results shows that only 1% of the accidental scenarios have more than 2,000 m of hazardous distance, with the possibility of reaching the nearby communities, located around Camaçari Industrial Complex. All the remained scenarios, 99%, have their effects limited to the industrial sites in Camaçari.

Finally, for the Phase 3 – Quantitative Risk Analysis (QRA), per APPOLO 2 risk matrix, all scenarios classified as Pre-Analysis and Confirm Risk, must be assessed using QRA methodology. It has implied that 30% of the 52 companies initially analyzed by the preliminary hazard analysis (PHA) and road transportation and pipe ways between the Complex sites have conducted QRAs. The software SAFETI [7] was used on the study.

The results for the QRA showed that, among the 90 process units, storage areas and transportation systems evaluated, 77% of them were classified as acceptable, 16% as ALARP and 7% as not acceptable. Due to these

results, for the 23% of the analysis with risk different from acceptable, reduction measures were proposed and the risk was review to consider the implementation of them. Finally, with the mitigation, 86% of the units were considered with acceptable risk (increase of 9% after risk mitigation) and the remaining 14% as ALARP.

No unit has remained with not acceptable risk, after the evaluation of mitigation, that was based on reduction of inventory, installation of new blockage systems and interlocks and improvement of the reliability of safety instrumented systems. All recommendation from the QRA were reported to the local environmental agency and included in the status report, issued annually by the companies.

Additionally, significant efforts were giving on increase the competence in risk assessment and risk management for the Camaçari Complex professionals, with several training classes performed and over 600 trained people.

APPOLO 2 Project must be considered as one of the most relevant and complete risk assessment studies ever done, due to its centralized approach and coordination that has implied in the use of common methodology for all 52 companies included in the study. A few relevant conclusions can be extracted from the study:

- Proximity of each site in the complex leading to a high probability of dangerous effects from one company reaching neighboring ones, increasing the necessity of constant reviews of the Emergency Plan of each site;
- Considerable distance of 2,000 m, from most of the facilities to the community and the urgent need of actions to preserve the dense vegetation located around the complex, due to its importance in maintaining the gap between industrial and residential areas;
- Centralize management of pipe ways located in the complex, that connect the several companies, with the coordination of raw material unit, and establishment of technical committee to ensure that all safety measures are being take care by;
- New technologies and revision of inspections plans, to increase the integrity of process equipment and storage vessels and tanks, considering the 28 years of operation of Camaçari Industrial Complex;
- Increase of the use of risk analysis as a support for the management of process changes; support from all companies, including administration level and technical professionals;
- Increase of safeguards to avoid soil contamination and reduction of existing passive.

APPOLO 2 Project can be considered as a first initiative in Brazil, allowing all companies involved in getting permanent and systematic control of their risks, using the Risk Management Program as a standard.

2.5. Risk Management Program Development and Implementation

Complementing the results from APPOLO 2 Project, during the definition of the Technical Specification of the study, in 2000, the Technical Steering Committee has indicated that the development of the risk assessment studies should become a more continuous activity and a more systematic approach should be used.

It was suggested, and approved by local authorities, that each company should develop and implement a Risk Management Program (RMP). The outline of the program is based on ten critical elements, as following:

1. Process Safety Information
2. Risk Assessment
3. Operational Procedures
4. Training
5. Sub-contractors
6. Integrity and Maintenance
7. Management of Changes
8. Incidents and Accidents Investigation

9. Emergency Planning/Evacuation and Emergency Response Procedures
10. Auditing Process

The process of development and implementation of the RMP started after the conclusion of the risk assessments of risk assessments in 2005. Considering that in Camaçari Complex, there were at that time 52 companies that should implement the RMP and that different levels of culture towards process safety existed (from totally dependent companies, that didn't have any initiative on process safety to international and very well developed sites, with process safety programs already implemented), COFIC has developed with support from the Steering Committee and DNV GL a guide for implementation of the RMP.

This guide has detail description of each element, with focus given to goals, objectives, documents or procedures related to the implementation of each of the aspects for the protection of safety and environment. Also, a PDCA cycle, indicating activities that must be performed for implementation and an audit protocol, to support the verification and progress review of the implementation are included on the guide.

As part of APPOLO 2 Project and to obtain the operational license of the Complex, each company had to present the level of compliance with the RMP. A first gap analysis was performed with most of the companies and action plans were developed, with an aim to have the conclusion of implementation process in a five-year period.

In 2007, the Risk Management Program has been extended to include the pipeline transportation systems in the Complex and main interconnections with export Terminal, located 35km from the Camaçari.

In 2008, the hazardous materials road transportation mode has been included on the RMP, with a new guide developed and gap analysis done for the main transportation companies operating in Camaçari. This program should be applied to all companies that transport dangerous good on the limits with the complex.

Today, annually, each company should present to COFIC an update of the status of the implementation of the program, as a requirement of its operational license. The information is then reported to the environmental agency that can follow closely with the companies the actions and verify in loco, if needed.

2.6. Emergency Planning and Contingency

Emergency planning is one of the most important activities conducted by COFIC and centralized on the Complex. Directives with requirements for communication of risk, risk statistics, training for brigades and firefighting/rescue workers, crisis management and others are in place [8].

A Contingency Plan that contemplates the accidental scenarios with possibility to extend beyond the limits of the complex is developed and implemented by COFIC. Other scenarios that have effects limits to the Complex are under management of each responsible company.

As support to planning for emergencies Camaçari Complex has implemented today the following initiatives:

2.6.1.Emergency Medical Plan (PAME)

This program provides medical emergency assistance for the companies. It is formed of specialized professionals (physicians and nurses), ambulances (IC units), modern equipment for life support and service agreements with hospitals and clinics. It has a centralized emergency center, where initial medical treatment can be given and with adequate transportation provided to local hospitals.

This initiative guarantee a uniform treatment to any injured person, correct treatment in case of contact with chemical toxic products, considered the high level of specialization of the medical team, which, being centralized, minimize local efforts of each company.

2.6.2.Mutual Aid Plan

Through the Mutual Aid Plan (PAM), any company installed within the limits of the Complex can request prompt support from other companies in emergency situations. It involves human and material resources from the companies, such as medical staff, firefighting brigades, emergency equipment, etc. A pioneer in Brazil, such system reflects the high concern with safety issues in the Complex.

2.6.3. Emergency Drill and Evacuation

Starting in 1998, yearly, an emergency drill and evacuation of the whole Camaçari Complex workers is established. The scenarios under evaluation are from the Internal Contingency Plan and each year one of the involved companies in the main scenarios identified is responsible to conduct the drill, with support from COFIC. The evacuation involves more than 18.000 workers and the technical support provided by health and safety professionals from all companies.

2.6.4. Emergency Control Training Center

COFIC is responsible for the Emergency Control Training Center – CTCE, which is the most complete in Brazil, with a firefighting simulation unit and capacity to train about 3.000 individuals per year.

2.7. Initiatives with the Communities

Around Camaçari Complex, are located two main communities, Dias D'Avila and Camaçari, Dias D'Avila are located 4 km from the complex and has 80.700 habitants [9] and Camaçari is 2 km, with around 297.000 habitants [10].

COFIC has been promoting the inclusion of these communities in the activities of industrial complex and several initiatives are now in place. The development in 1996 of the first Community Development Center – NUDEC started with the aim of maintain a constant dialogue with the neighboring communities, expand and strengthen the relationship between the Complex and the nearby communities in a very concrete way.

Some of the initiatives are indicated on the next sections.

2.7.1. Community Advisory Council

The Community Advisory Council is a formal channel of dialogue between the companies and the communities surrounding the Camaçari Industrial Complex.

Composed of 24 representatives from different community and society sectors, this council meets on a bimonthly basis to discuss matters of mutual interest related to community, primarily in the areas of safety, health, environment and social responsibility.

2.7.2. Visit Program

The Camaçari Industrial Complex frequently receives visitors from other countries, from other Brazilian states and from the neighboring communities interested in getting acquainted with their activities or interested in establishing business relationship.

The program designed for visits by members of neighbor communities are coordinated by COFIC and involves mainly students, teachers and community leaders from Camaçari and Dias D'Avila.

2.8. Emergency Drills with Communities

The first emergency drill with the participation of the communities was held in Camaçari, in December of 2006. It had a participation of govern agencies as hospitals, emergency rescue team, police and local leaderships.

The objective of these drills is to demonstrate for the communities the actions that need to be taken in case of emergency involving chemical products.

3. CONCLUSIONS

Looking to the future, over the 20 years of progress, a sustainable and continuous implementation of Risk Management Program has been achieved. It is important to keep with the integrated and common approach for the complex. Maintaining the constant contact and exchange of experiences is very valuable for a loss prevention and much needed philosophy.

Process safety, represented by the RMP developed and implemented by COFIC is now a reality and is being followed by all new companies that want to be installed in Camaçari Complex. As well, it represents a continuous building of sustainable culture for involved companies.

Safety performance of the companies installed in Camaçari is the best in Brazil, regarding accident without leave and has one of the lowest accident rates in the world [12].

The safety index, represented in Figure 3, achieved by Camaçari Complex is lower than the Brazilian average (indicated by Brazilian Association of Chemical Industries – ABIQUIM) and has been reducing, being a clear reflection of the practices implemented on complex.

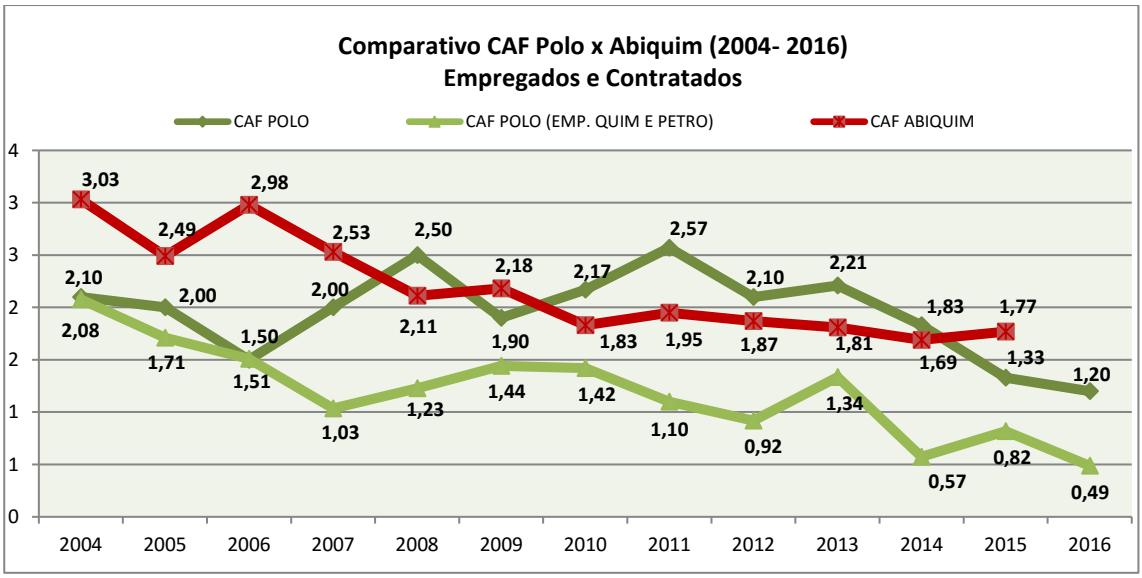

Figure 3: Rate of Accident with Loss of Time (ABIQUIM x COFIC) [2]

Besides that, looking to the successful case of APPOLO 2 Project, risk assessment and risk management is an established legal requirement for all companies to be installed and under operation in the State of Bahia, showing that this best practice is being followed through the state

Camaçari Complex, with COFIC's coordination, has experienced the development of a process safety culture over the last 25 years. The results obtained regarding process safety reflect the high level of commitment from the leadership teams of all associated companies.

As a summary of the main initiatives of the Camaçari Industrial Development Committee, there are:

- Pioneered the implementing of an integrated system for Environmental protection.
- HSE (Health, Safety & Environment) performance exceeds the regulatory standards.

- Most complete risk analysis study carried out in Brazil, involving all companies installed in the Industrial Complex – APPOLO Project.
- HSE audits in all companies (Awards in HSE).
- Risk Management Program is implemented in all companies, including transportation of chemicals.
- Continuous interface with the Environmental agencies, that includes the recently published review of Bahia's Risk Assessment Standard [11].
- Continuous dialogue with neighbor communities through COFIC Community Advisory Council.

Opportunities for upgrades on the processes implemented and under implementation always exist and COFIC is looking to the new technologies, methodologies and best practices that can intensify their leading position in process safety management in Brazil, combining the commitment of both leadership and workers, the successful exchange of experience from all and ability to work as a team towards loss prevention in every aspect.

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