Procedure for Technological Diagnosis of Oily Residuals Management in Cubans Distributed Generation Power Plants

10th International Conference on Through-life Engineering Service
16-17 November 2021, University of Twente, The Netherlands

Procedure for technological diagnosis of oily residuals management in Cubans distributed generation power plants

David Javier Castro Rodríguez[a], Omar Gutiérrez Benítez[b], Jelvys Bermúdez Acosta[c], José Reinol Poma Rodríguez[b], Micaela Demichela[a].

[a]*Politecnico di Torino, Corso Duca degli Abruzzi, 24, 10129, Turin, Italy.*
[b]*Centro de Estudios Ambientales de Cienfuegos, Street 17 corner 46 Avenue, w/n, Reina, 55100, Cienfuegos, Cuba.*
[c]*Greeng S.R.L., Cerro Porteño C/ Próceres de Mayo No. 1258, Asunción, Paraguay.*

* David Javier Castro Rodríguez Tel.: +39-351-160-6069; *E-mail address:* david.castro@polito.it

Abstract

In Cuba, more than 50 % of the electricity generation capacity is based on small-scale distributed power plants, which guarantee the energy supply demand from fossil fuels. Several negative environmental impacts are associated with this, including contamination by oily residuals. The purpose was to diagnose oily residuals management in Cubans distributed generation power plants from a technological approach. Ten generating power plants from Cienfuegos territory were selected as a case study. A methodological procedure, supported in the general method of problem solving was designed. The environmental audit was used as a fundamental tool for the verification of technical requirements regarding the containment, collection, evacuation, treatment, and final disposal of oily waste. For deployment of causes identified as evidence of auditory, failures modes and effects analysis (FMEA) were used. Hydrocarbon concentrations at sampling points in the external environment frequently exceeded the threshold. Hydrocarbon spills, clogging and waste load increased in the treatment system, were the most frequent failure modes and could manifest themselves from the occurrence of more than 150 causes. From this group, a set of common causes inherent to each power plant was identified. A package of corrective actions was designed, which constituted conceptual ideas for improving environmental performance. The procedure was generalized to other power plants in the country, contributing to sustainability in the generation of electricity in Cuba.

Keywords: Distributed generation power plant; environmental audit; FMEA; oily residuals.

1. Introduction

The 2030 Agenda for Sustainable Development presents an ambitious vision of sustainable development and integrates the economic, social, and environmental dimensions in a set of Sustainable Development Goals (SDGs). Within its SDGs, the technological progress is recognized as a key to finding lasting solutions to both economic and environmental challenges. Promoting sustainable industries, and investing in scientific research and innovation, are all important ways to facilitate sustainable development. Specifically, issues such as the development of quality, reliability, resilience, infrastructure improvement and retrofit industries, as well as the more effectively use of resources and the adoption of clean and environmentally sound industrial technologies, supports the economic development and human well-being. Inside of this context, the adoption of ecologically sound management of chemicals and all wastes throughout their life cycle, and significantly reduce their release, in order to minimize their adverse effects on human health and environment, are also central issues to achieve sustainable development [1].

Nowadays, hydrocarbons are broadly used in the society, and it is associated with multiple activities that include exploration, transportation, processing, commercialization, and exploitation [2]. This intense consume brings associated the imminent risk that releases on the environment of this hazardous substance may occur, with implications which can be amplified its damaging effects caused by not only the aging phenomenon, but also interacting with other risks factors [3].

From their side, the Cuban National Environmental Strategy states that in the country there is a significant degree of environmental pollution, with a significant impact on the state of different components of the environment and people's quality life. Regarding this issue, multiple factors have been associated with the pollution, such as: insufficient coverage of waste treatment; technological indiscipline and non-compliance with repair and maintenance cycles; low level of introduction of preventive practices and strategies

Peer-review under responsibility of the Programme Chair of the 10th International Conference on Through-life Engineering Services.

aimed at reducing the generation of residuals and emissions at the source of origin; the insufficient degree of training and raising awareness at all levels of the production and service organization; the limited budget and material resources for prevention investments; poor reduction and control of pollution.

In Cuba that it is neither developed country, nor has a high industrial development, have been implemented government programs in order to develop actions for energy improvement. Electrical energy generation as close as possible to the site of the consumption, is one of the technological alternatives that the country has adopted. Indeed, more than 50 % of the electricity generation capacity is based on small-scale distributed generating plants, which use fossil fuels to guarantee the electrical energy demanded by the industrial and residential sectors, triggering negative effects on the environment from their impacts [4].

Moreover, in life cycle analysis research of distributed generation of electricity in Cienfuegos territory, was recognized that little attention has been paid on the environmental and human health impacts associated to the distributed generation of electricity in Cuba [5]. On the other hand, the hydrocarbon pollution in soils and waters have been identified as negative environmental impacts associated with the execution of generation processes, fuel purification as well as repair and maintenance of equipment, in power plants of the distributed generation network in that country [6].

Given all above, the technological diagnosis of oily residuals management in Cubans distributed generation power plants played an important role in order to cope the potential pollution, and the environmental and human health impacts associated with this factor. Hence, to implement a procedure which could achieve this purpose was the research goal.

2. Methodology

2.1. Case study

The power plants from Cienfuegos province were selected as a case study. There are ten generation plants distributed in the territory, eight plants are fueled with diesel (“Antonio Sánchez”, “Arimao”, “Balboa”, “Hormiguero”, “Junco Sur”, “Juraguá”, “El Tablón” and “Cruces”) and two with fuel-oil (“Yaguaramas F-O” and “Cruces F-O”). The fuel-oil power plants have Hyundai technology of 1.7 MW and operate uninterruptedly connected to the National Energy System (SEN, in Spanish) [7]. In the figure 1 can be appreciated the power plants location in the territory of Cienfuegos, Cuba.

On the other hand, the eight diesel plants constitute reserve generating plants for peak hours, when there is a high demand for energy. These diesel plants present different configurations of MTU ~ 4000 and MTU ~ 2000 technology engines [5]. Specifically, the generation of oil sludge and oily liquid waste in these facilities come from the purification (centrifugation) of fuel, as well as from the purges of fuel storage tanks, accidental spills in fuel loading and oil transfer operations, breakdowns, scrubbing plants in workshops, management of used oils, among other activities [8].

Fig. 1. Location of power plants in Cienfuegos province, Cuba.

2.2. Procedure

The current investigation involved the implementation of a procedure based partly on the eight steps in the problem solution. These steps, applied to improvement projects, enable to reach the root causes, and do not stop at attacking effects and symptoms [9]. In addition, some adjustments were introduced to the original procedure principally with the addition of tools combined under the principle of methodological convergence. Beforehand, the environmental audit was included as a corner stone of the procedure first step (Identifying the problem). This selection guaranteed the identification of environmental risks or impacts in a systematic, independent, and documented process that allows obtaining evidence and evaluating it objectively, in order to determine the extent to which criteria are met [10]. Furthermore, the environmental audit prints much more robustness to the research than an isolated monitoring which just offer a static characterization of the situation. Consequently, it was necessary to focus on the management of oily residuals as an auditory goal. In this context, the audit was executed in accordance with the guidelines established for the audit of management systems [11]. The figure 2 shows the sequence of steps used in a heuristic diagram.

2.2.1. Definition of Audit Criteria

First, it was necessary to identify the problem. In consequence the audit criteria consisting of the set of policies, procedures or requirements used as reference, were systematized. A background documentary (technical, internal, standards) review was carried out. The principals documents reviewed were: environmental licenses; reports of environmental licenses; hazardous waste management plan; reports of the environmental inspection state; technical projects of basic and detailed engineering, in particular hydraulics and oily wastewater treatment systems projects, including the plans of all its elements and component organs, pipelines; characterizations of the previous oily wastewater; manual of procedures and instructions; management manual for distributed electricity generation; procedures, instructions, operation and maintenance records for oily wastewater treatment systems; state of professional competences of managers, specialists and operators from the environmental point of view.

Additionally, the follow national and international standards were consulted: NC 819: 2017 "Management of the button residues of storage tanks for oil and its derivatives"; NC 27: 2012 "Discharge of wastewater to land waters and sewerage-Specifications"; NC TS 1067: 2015 “Petroleum industry - Used lubricating oils. Specifications"; NOM-138-SEMARNAT / SSA1-2012 "Maximum permissible limits of hydrocarbons in soils and guidelines for sampling in the characterization and specifications for remediation."

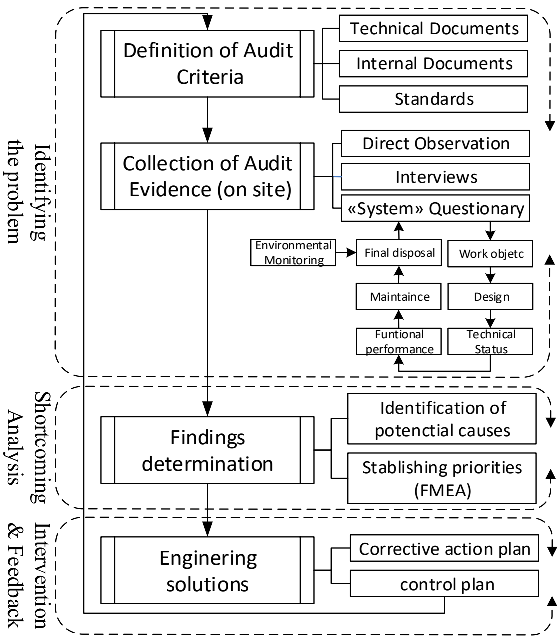


Fig. 2. Heuristic diagram of the research procedure.

2.2.2. Collection of Audit Evidence

Second, the audit evidence was collected. It consisted of records, statements of fact and information pertinent to the audit criteria, thus complying with the requirement of being verifiable. To achieve this stage, on-site activities were carried out and the following techniques were used: (i) Direct observation: tours were carried out through the physical areas of the entity and its surroundings, collecting all the information from interest, taking photographic evidence and geographic coordinates. (ii) Interviews: managers, specialists, operators, and neighbors were interviewed. It was used a less standardized interview focused on the problem studied as recommended [12] (iii) Sketches, maps, and flow charts: Sketches, maps, and flow charts were developed to complement and systematize the information collected in the field work. (iv) Questionary: The questionary explained by Terry, Gutiérrez & Abó [13], was identical applied for the environmental inspection of the wastewater treatment and final disposal systems.

From this questionary, the identification and of the system for the containment, collection, evacuation, treatment, and final disposal of oily waste (hereinafter "system") was carried out, following the criterium of Costantino, Di Gravio & Tronci [14] who state that specific methodologies are required to focus audit activities on the most critical elements. This analysis considered the following factors: the work object and the physical area occupied; the design requirements; the technical status; the criteria of the functional performance; operating conditions and maintenance aspects; as well as final disposal.

Regarding this last issue, the receiving bodies in the environment and the wastewater disposed to them were characterized. To do this, total petroleum hydrocarbons (TPH) by gravimetric method [15] were measured out in 32 sampled points of soils surrounding the power plants under analysis. The sampling selection was considered a non-random procedure, where the expert selection was chosen as the criterion as described by Castro et al. [16] considering also the complexity and the work regime of each plant. Decisions were based fundamentally on the physical elements selectable for taking samples, their location, the homogeneity of the matrix and the pollutant to be analyzed. The scope of the sampling program was limited by economic and logistical criteria as well as ethical issues such as the privacy. Integrated monitoring of risks for Seveso plants criteria were also considered, in agreement with the described by Baldissone et al. [17].

2.2.3. Findings Determination

Shotly after having a clear problematic identified from the instituted audit criteria and evidence obtained; then, qualitative, and quantitative analyzes were established in order to identify the probable causes of the oil pollution. These causes were generated by the technique of brainstorming and then plotted on a cause-and-effect diagram to display a wealth of information in a compact space as recommended Gutiérrez & de la Vara [9]. In the construction of the diagram, the method of enumeration of causes was applied, previously stratifying by work object and later by subsystem, considering potential causes and grouping them by similarity.

Immediately after the identification of the causes, the most important ones were prioritized with a risk-based decision-making strategy according with the criterium of Demichela et al. [18]. For doing so, the failure mode and effect analysis tool (FMEA) and its risk priority number (RPN) was used, which manifests itself in the interval from 1 to 1000, because of the multiplication scales of severity, occurrence and determination [9]. The findings which presented a RPN ≥ 600 were considered with a major priority.

2.2.4. Engineering Solutions and Feedback

At the end, a corrective action plan was developed which consisted in a package of engineering solutions, including the Cleaner Production (PML) options to minimize, in the sources of origin, the generation of oily residuals. A control plan was designed in order to monitoring the corrective action implementation.

Afterwards the feedback of the procedure implementation was documented, connecting the end of the procedure with a new beginning in order to ensure the cycle of continuous improvement.

3. Results

3.1. Identifying the problem

As a result of both, cabinet work and on-site activities, the system of each power plant was stratified in functional subsystems for simpler analysis. In the figure 3 can be appreciated the example of “Cruces F-O” power plant, with the aim to illustrate the adopted approach.

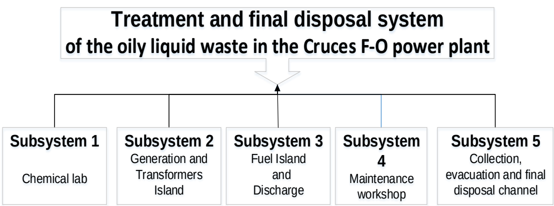


Fig. 3. “Cruces F-O” power plant functional subsystems.

From an exhaustive diagnosis in the power plants subsystems, attending to the criteria of design requirements, technical status, functional performance, operating conditions, and maintenance aspects; an abundant amount of evidence was documented. This evidence was collected among pictures, sketches, check sheets, reports, and notes. In the Appendix A is shown a sampled of some pictures as primary evidence collected in the power plants. In the table 1 is presented the frequency of shortcomings between evidence collected and stablished audit criteria to each power plant. In addition, from the environmental monitoring program were reported several points with traces of TPH behind the final disposal points to each power plant.

Table 1. Frequency analysis of findings in power plants and analytical monitoring report.

Power plant	Point	TPH ($mg \cdot kg^{-1}$)	Findings Frequency
Antonio Sánchez	1	1.80	24
	2	14.40	
	3	0.32	
	4	0	
Arimao	5	0	30
	6	0	
	7	9.50	
	8	9.20	
Balboa	9	1.15	26
	10	0.87	
Hormiguero	11	1.91	27
	12	0.75	
	13	0.37	
	14	0	
Juraguá	15	0.30	23
	16	0	
	17	0.70	
El Tablón	18	0	23
	19	0	
	20	0	
	21	0.44	
	22	0.12	
	23	0.44	
Cruces	24	0.70	31
	25	0.45	
	26	46.00	
	27	0	
Junco Sur	28	2.30	17
Cruces F-O	29	3.30	95
	30	3.50	
	31	18.70	
	32	5.40	

The evidence of hydrocarbons traces into the natural environment indicated a gap of this criterium respect to established standard limit (NOM-138-SEMARNAT / SSA1-2012). The limit depends on the use of the soil in any case.

The hydrocarbon pollution was translated into the ineffectiveness of the oily waste treatment systems, which is strongly associated to the findings identified during the environmental audit, related with the design requirements; the technical status; the criteria of the functional performance; operating conditions and maintenance factors.

3.2. Shortcomings Analysis

The findings determination allowed to find the potential associated causes (see an example in appendix B), which immediately were deployed throughout the failures modes and effects analysis obtained the most critical causes according to the RPN. Were identified more than 150 independents causes totaling all power plants. Particularly, it is remarkable that a set of common causes inherent to each power plant with RPN higher than 600 were identified. These group is listed below:

- Lack of procedures for storm drainage from the tank's buckets.
- Lack of cleaning and maintenance actions in the treatment organs.
- The levels of supernatant hydrocarbons are not measured within the separation organs.
- There is no record of effluent control downstream of the hydrocarbon traps.
- The hydrocarbon traps feed pipe is at a surface level and without a submerged elbow.
- Deficiencies in interconnections and non-compliance with the recommended immersion height and diameter requirements.
- Treatment organs with poor waterproofing.
- The fuel discharge area lacks elements for containment and collection of hydrocarbons, in the case of accidental spills.
- The storm drains valves remain closed, the storm water drainage from the tanks bucket is carried out suddenly, causing turbulence problems in the flow.
- Operators' negligence and lack of technological discipline. Bad practices.
- Final disposal tube in the hydrocarbons trap is partially buried.
- The interconnecting tube between compartments of the trap does not have a ventilation.
- There is no control record for the oil room effluent.
- Hydrocarbons spills on the pavement and storm drainage channels.
- Parts washing with direct discharge to the rain drains in the engines area.
- Rain canals obstruction with rags, sediment, and other solids.
- Lack of containment elements in areas where fuel is managed.
- Fuel channels without hydrocarbon trap before final discharge.
- The water level in the oil pits is not controlled.
- The oily water purges from the compressors discharge directly to the ground.
- The hydrocarbon trap does not have a pump for transferring the supernatant to the sludge tank.
- There is no area for the treatment of sludge and sediments contaminated with hydrocarbons.
- Pipeline system levelling problems.
- Problems of civil construction of collector canals.
- Technical deficiencies in the design dimensions of the waste treatment organs.
- Hydrocarbon traps work overload due to non-segregation of rainwater and oily water.
- Canals on land without waterproofing.

3.3. Intervention

A package of 276 corrective actions was designed which have been represented a guideline for the stakeholders of the Territorial Electric Enterprise in order to manage the environmental performance of the distributed generation in Cienfuegos, Cuba.

Specifically, short-term implementation solutions were related to management of organizational aspects, and the adoption of good maintenance practices. The proposed medium-term solutions which required investment had a conceptual engineering ideas scope.

Finally, for illustrative purposes, are shown in the Appendix C, a pair of specific sketches of the engineering ideas proposed in different power plants.

4. Conclusions and Feedback

The procedure implementation in the distributed generation power plants of Cienfuegos, not only contributed to the awareness about several shortcomings regarding the oily waste management in the plants of the territory, but also have generated a framework to manage these shortcomings. The framework has been constituted a dynamic instrument to the stakeholders and is generalizable throughout further research to other power plants.

The principal failures modes and causes associated with technical and organizational shortcomings were objectively assessed. Furthermore, an intervention plan of 276 countermeasures was stablished.

The results also contributed to achieve the sustainability in the distributed generation of electric power plants in Cuba, mitigating the release of chemicals into the environment.

References

[1] ONU_United Nations Organization. Transforming Our Worl: The 2030 Agenda for Sustainable Development. A/RES/70/01. 2015. pp. 1-40.

[2] Cocârtă, D.M., Stoian, M.A. y Karademir, A. Crude Oil Contaminated Sites: Evaluation by Using Risk Assessment Approach. Sustainability. 2017; 9: 1365 105-11 ISSN 2071-1050. pp. 1-16

[3] Pérez, J., Vigueras, S., Zamudio, E., Rivera, N, Calva, G. Bioremediation of soils from oil spill impacted sites using Bioaugmentation with biosurfactants producing, native, Freeliving nitrogen fixing bacteria. Revista Internacional de Contaminación Ambiental 2017. 33: 105-11 ISSN 0188-4999. pp. 105-114.

[4] Llanes, E. Análisis del ciclo de vida como herramienta para la evaluación del comportamiento ambiental de un proceso. Caso de estudio central eléctrica de fuel oil 110 kv en la provincia de Granma-Cuba. Revista Científica y Tecnológica UPSE. 2017; Vol. IV No. 2, p. 37-45, ISSN 1390-7697.

[5] Rodríguez, B., Fernández, M. y Fernández, N. Análisis del ciclo de vida de la generación distribuida en la provincia de Cienfuegos. Ingeniería Energética. 2014; XXXV: 3, p. 274-285.

[6] Medel, G., García, L., Hernández, C. y Medel, M. Procedimiento para la evaluación del desempeño ambiental: aplicación en el sector energético cubano. Gestão & Produção. 2015; 22: 3 São Carlos ISSN 0104-530X. pp. 1-17.

[7] O. Gutiérrez, Castro D., J. Bermúdez and J. Poma. Diagnóstico del sistema de tratamiento de residuales oleosos de la central eléctrica de fuel oil de Cruces, Cuba. Second Congress of the Mexican Association of Engineering Science and Environmental Management. AMICA 2015.

[8] Castro D., O. Gutiérrez, J. Bermúdez and J. Poma. Auditoría del manejo de residuos oleosos en un grupo electrógeno de diésel. Revista Tecnología Química- 2020; 40: 2. Pp 241-259.

[9] Gutiérrez, H. y De la Vara, R. Control estadístico de calidad y seis sigma. 3ra ed. México: Mc Graw Hill. 2013. ISBN: 978-607-15-0929-1.

[10] de Carvalho, S. A., Costa, C. y Pilau, L.L. Auditoria Ambiental ou Ecoauditoria: Um Instrumento de Sustentabilidade e Gestão Ambiental. Revista FSA (Facultade Santo Agostinho). 2016; 13:3, Art. 7, p. 125-143, mai./jun.

[11] International Standard Organization. Guidelines for auditing management systems. ISO 19011, 2018. Ginebra, Suiza.

[12] Rezvani Z., Hudson P. How do middle managers really make decisions within the oil and gas industry? Safety Science, Vol. 139. 2021, 105199. ISSN 0925-7535.

[13] Terry, C. C., Gutiérrez, J. y Abó, M. Manejo de aguas residuales en la gestión ambiental. 1ra ed. La Habana, Cuba: Centro de Información, Gestión y Educación Ambiental (CIGEA), 2010. Pp. 1-121. ISBN: 978-959-287-023-9.

[14] Costantino F., Di Gravio G., Tronci M. Environmental Audit improvements in industrial systems through FRAM. IFAC-PapersOnLine. 2018. Pages 1155-1161. ISSN 2405-8963.

[15] EPA Method 9071B, 1998. N-Hexane Extractable Material (HEM) for Sludge, Sediment, and Solid Samples, Revision 2.

[16] Castro D., O. Gutiérrez, J. Poma, J. Bermúdez, M. Demichela. Environmental monitoring in a Cuban oil storage plant to characterize the hydrocarbons pollution exposure in the fence-line community. Proceedings of the 31st European Safety and Reliability Conference. Published by Research Publishing, Singapore. ISBN: 978-981-18-2016-8.

[17] Baldisone, G., L. Comberti, M. Demichela, T. Marcon, E. Plot, and M. C. Leva. Integrated monitoring of risks for Seveso plants. Safety and Reliability - Safe Societies in a Changing World - Proceedings of the 28th International European Safety and Reliability Conference, ESREL 2018. Trondheim; Norway. pp. 1909-1914.

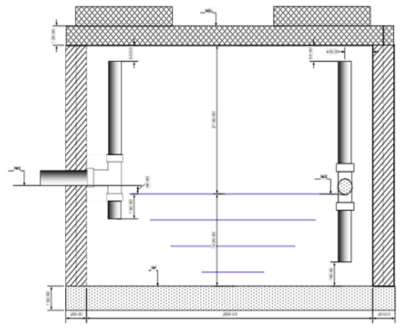
[18] Demichela M., Baldissone G., Camuncoli G. Risk-Based Decision Making for the Management of Change in Process Plants: Benefits of Integrating Probabilistic and Phenomenological Analysis. Industrial & Engineering Chemistry Research 2017. 56 (50), 14873-14887. DOI: 10.1021/acs.iecr.7b030

Appendix A. Some graphical evidence from on-site audit activities in different power plants.

Appendix B. Cause-Effect diagram by subsystem in the Cruces generation power plant.

Appendix C. Some graphical evidence from onsite audit activities.

C.1. Design criteria for the hydrocarbon trap remodeling in the Cruces diesel generator power plant.



C.2. Conceptual ideas layout to mitigate the hydrocarbon pollution in "Hormiguero" diesel generator power plant.