

Industrial safety analysis based on national and international standards for the operation of boilers in Mexico

Análisis de seguridad industrial basado en normas nacionales e internacionales para la operación de calderas en México

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Abstract

At present, there are still explosions caused by boilers, either due to lack of maintenance or because of poorly qualified personnel to operate them, causing human and economic losses and environmental damage. In Mexico, the government authority responsible for the protection and promotion of employment is the Secretary of Labor and Social Security (STPS), the regulations they manage are known as Official Mexican Standards (NOM). The regulation that establishes the safety requirements for the operation of boilers is NOM-020-STPS-2011. The objective of this research is to analyze referred standard, adequately promote its use and propose a sustainable maintenance plan. This was carried out under a mixed approach, analyzing quantitative and qualitative parameters considering statistical and technical data, it was also necessary to assess the norm through cause-effect laws. This paper aims to promote the use of safety measures for the efficient and sustainable use of boilers to generate a culture of compliance with international standards and preserve the important factors of this sector.

Boiler, Industrial Security, Standard-Sustainable

Resumen

En la actualidad aún se presentan explosiones ocasionadas por calderas, ya sea por falta de mantenimiento o por personal poco calificado para operarlas, provocando pérdidas humanas, económicas y daños ambientales. En México, la autoridad gubernamental responsable de la protección y promoción del empleo es la Secretaría de Trabajo y Previsión Social (STPS), administra las regulaciones conocidas como Normas Oficiales Mexicanas (NOM). La normatividad que establece los requisitos de seguridad para el funcionamiento de calderas es la NOM-020-STPS-2011. El objetivo de esta investigación es analizar dicha norma, promover adecuadamente su uso y proponer un plan de mantenimiento sostenible. Esta fue realizada bajo un enfoque mixto, analizando parámetros cuantitativos y cualitativos considerando datos estadísticos y técnicos, igualmente fue necesario la apreciación de la norma mediante leyes causa-efecto. Esta investigación pretende promover el uso de medidas de seguridad para uso eficiente y sustentable de calderas para generar una cultura de cumplimiento de estándares internacionales y preservar los factores importantes de este sector.

Caldera, Seguridad Industrial, Norma-Sostenible

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Introduction

At the end of the 18th century, the first industrial boilers began to be manufactured, these operated at greater pressures than atmospheric. Therefore, when equipment failed, often, results turned catastrophic. *American Society of Mechanical Engineers [ASME]. (s.f.)*

Until the middle of the 20th century, productive aspects such as design, quality and reliability of the product and the process were considered more important than industrial safety, because it was thought that this could be achieved by being careful and that it did not require planning and design. Safety was not considered a key factor in the production process. *Asfahl, C. et.al. (2010)*.

Currently, the International Labour Organization (ILO) establishes that workers must be protected against accidents caused by their work. However, for millions of workers it is far from being a reality. Global ILO estimates show that 2.78 million work-related deaths occur each year. *International Labour Organization. [ILO]. (2018)*.

In Mexico, the institution in charge of complying with safety requirements is the *Secretaría de Trabajo y Previsión Social (STPS)*. Among the standards managed by this secretariat is the Official Mexican Standard NOM-020-STPS-2011, which is focused on pressure vessels, cryogenic vessels and steam generators or boilers. *Secretaría de Trabajo y Previsión Social [STPS]. (2011)*.

This paper aims to analyze the current situation of boilers in Mexico, as well as promote the proper use of the Official Mexican Standard NOM-020-STPS-2011 and propose a sustainable maintenance plan. Boilers are equipment that requires constant maintenance and monitoring, because, the explosions that can be caused by them could have important consequences in developing countries, not only destroying property and human lives, but also ruining livelihoods. This research aims to promote the use of standards and safety measures for the efficient and sustainable use of boilers. *Akshoy, P. et al. (2018)*.

Methodology

This research was carried out under a mixed approach, because a quantitative and qualitative methodology was used, based on National and International Standards focused on boilers, as well as articles and books on industrial safety. Currently, there are still explosions caused by boilers, either due to lack of maintenance or because of poorly qualified personnel to operate them, causing human and economic losses and environmental damage. The quantitative approach was required to analyze statistical parameters, technical and operational data to identify the deficiencies of industrial safety in the work centers. However, the qualitative method is equally necessary for the appreciation of the normativity through cause-effect laws, providing depth to the data, interpretive richness and contextualization of the environment. Therefore, a sustainable maintenance plan is proposed to efficiently use the boilers, provide worker safety and generate a culture of compliance with international standards to preserve the important factors of this sector. *Hernández, R. (2010)*.

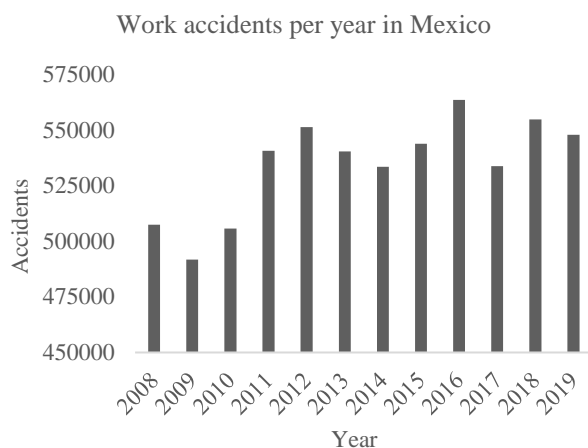
Safety and hygiene at work

The regulations define procedures and techniques that are applied in the work centers, for the recognition, evaluation and control of harmful agents that intervene in the processes and activities; with the aim of establishing measures and actions for the prevention of accidents. *Arellano, J. et al. (2013)*.

Work safety in Mexico

The Mexican Institute of Social Security (IMSS) represents 79.7% of the working population with formal employment in Mexico, which is why the Database of Labor Risks that it administers is relevant for statistical purposes at the national level. *Aguilar, C. (2017)*.

As can be seen in Graph 1, in Mexico there is an accident at work every minute, in the same way we can observe that from 2008 to 2019 the number of accidents remains at approximately 500,000 per year. This indicates that there is no interest in improving the labor security system in Mexico. *Instituto Mexicano del Seguro Social. [IMSS]. (2019)*.



Graphic 1 Work accidents per year in Mexico
Source: IMSS. (2019)

In the case of boiler / pressure vessel explosions, statistical data is difficult to obtain, because most industries keep accident / incident data of their equipment at home and it is not reported. *Agarwal, S. et al. (2017).*

The technical-commercial magazine “*Calderas...Guía del Usuario (en la industria y comercio)*” Year 1, No. 1, pointed out that during 2019, Mexico was the Latin American country with the highest number of reported accidents, with a total of 6, reaching 34 injured. However, in Mexico there is no exact record of explosions related to boilers / pressure vessels, therefore the number of accidents may be higher. *Combustión, Energía & Ambiente, S.A. (2020).*

Audits

Inspection systems safety and health at work can provide necessary information to make decisions during the administrative process of accident prevention. *Arellano, J. et al. (2013).*

Audits in Mexico

NOM-020-STPS-2011 establishes that audits can be done by verification units. These units (individual or legal entity) must be accredited and approved under the terms of the Federal Law on Metrology and Standardization, and they are in charge of verifying the degree of compliance with this Standard by issuing a conformity assessment opinion. *Secretaría de Trabajo y Previsión Social [STPS]. (2011).*

In Mexico, conducting audits of management systems Safety and Health at Work does not represent an attributable legal obligation to companies, however, it is an option that can adhere to ensure effective compliance with federal regulations concerning the functions and service activities Safety and Health at work. However, if they decide to carry out an audit process, they must comply with the requirements contained in Section 8 of the Official Mexican Standard NOM-030-STPS-2009 Preventive Health and Safety Services at work. *STPS. (2009).*

Boiler standards

ASME Code

A boiler explosion at the RB Grover shoe factory in Brockton near Boston in Massachusetts, USA killed 58 people and injured more than 150 in 1905. The explosion was so intense that parts of the equipment went through the floors and razed the four-story wooden building turning it into a crematorium. *Canavan, D.A. (2005).*

The Grover disaster triggered the formulation of the US National Boiler Code / Standard by the American Society of Mechanical Engineers (ASME), which governs the safe design, construction, operation, and maintenance of this equipment. Today, most national and international standards are based primarily on ASME boiler regulations. *Canavan, D.A. (2005). & Varrasi, J. (2011).*

Classification of pressure vessels according to ASME

As seen in Figure 1, according to ASME, vessels can be classified according to their intended service, service temperature and pressure, materials of construction, and geometry. *ASME. (s.f.).*

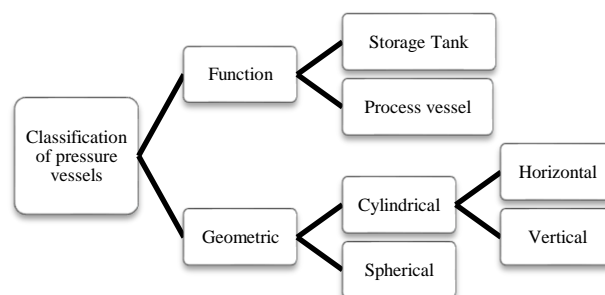


Figure 1 Classification of pressure vessels
Source: ASME. (s.f.).

The objective of using design codes is to avoid catastrophes that can affect human beings. The main Code used in Mexico, USA and many other countries of the world, is the "CODE A.S.M.E. SECTION VIII, DIVISION 1". This Code is published on a triannual basis; 1980, 1983, 1986, 1989, 1992, 1995, etc. León, J. M. (2001) and ASME. (s.f.).

Official Mexican Standard NOM-020-STPS-2011

In Mexico, the Official Mexican Standard NOM-020-STPS-2011 indicates the safety conditions for pressure vessels, cryogenic vessels, and steam generators or boilers. The objective of this standard is to establish the safety requirements for the operation of said equipment in the workplace, to prevent risks to workers and damage to facilities. STPS. (2011).

Boiler classification according to STPS

The Official Mexican Standard NOM-020-STPS-2011 classifies the equipment depending on its capabilities, and these turn into categories (Table 1). In Mexico, it is necessary to notify the *Secretaría de Trabajo y Previsión Social* about the use of pressure vessels located in category III. STPS. (2011).

Categories	Pressure	Thermal capacity
II	Less than or equal to 490.33 kPa	Less than or equal to 1,674.72 MJ/hr
III	Less than or equal to 490.33 kPa	Greater than 1,674.72 MJ/hr
	Greater than 490.33 kPa	Any capacity

Table 1. Categories for steam generators or boilers
Source: STPS. (2011)

Training

The Official Mexican Standard NOM-020-STPS-2011 indicates that workers who carry out activities of operation, maintenance, repair, and pressure tests or non-destructive examinations, must receive theoretical-practical training. The boss or owner of the equipment may contract a type "C" verification unit to provide training to the personnel. STPS. (2011).

According to NOM-020-STPS-2011, a boiler operator must:

- Define and interpret concepts such as operating pressure, maximum allowable working pressure, calibration pressure, operating temperature, thermal capacity, drawings or plans of the equipment, the signaling system for equipment and pipes, measuring instruments, values of safe operating limits.
- Identify the characteristics of toxicity, flammability, and reactivity of the fluid or fluids handled in the equipment.
- Recognize and address the risks generated by the pressure and temperature of the fluids in the equipment.
- Maintain within the established value the operating limits of the equipment and of any pressure relief device or safety element, as well as those variables that may affect them.
- Apply the procedures for operation, review, maintenance, repair, alteration, and pressure tests or non-destructive examinations of the equipment, as applicable.
- Apply the review procedures for pressure relief devices, safety elements, and control instruments, as applicable, including emergency stop operations.
- Control changes in the operating conditions of the equipment and/or the fluids they handle.

Adequate compliance with the Mexican Official Standard NOM-020-STPS-2011, and international standards as the ASME Code, are indispensable to ensure safety in the work area. Those assigned to the boilers must be thoroughly familiar with their operations to avoid exposing themselves and others to the risk of accidents. However, these rules are often flaunted or violated while being implemented at the grassroots level. The public and private sectors using the industrial, utility, and commercial boilers must recognize that the role of these laws is not simply to regulate commercial and industrial activity but to prevent accidents, injuries, illnesses, and loss of property. Akshoy, P. et al. (2018).

Accidents caused by boilers

Boiler explosions are very devastating, and many people die each year from these accidents. It occurs mainly due to the lack of training, awareness, and negligence of the industry owners, operators, and all management teams. Apart from these, there are some technical faults and over-operation in duty cycle or rated production. *Sharafat, A. et al. (2018).*

Specific reasons for boiler accidents

- Over pressurization of the equipment.
- Insufficient water in the boiler.
- Poor water treatment.
- Overheating and vessel failure.
- Improper construction or maintenance.
- Safety valve failure.
- Corrosion of critical parts of the boiler.
- Lack of trained personnel.

Recommendations for boiler safety

Proper maintenance, periodic inspection, and knowledge of boiler assistants and users make the equipment safer. In addition, managers must strictly follow the instructions below. *Akshoy, P. et al. (2018).*

- The boiler room must be surrounded by suitable fences.
- The equipment must operate with certified and efficient assistance.
- The water level in the boiler must be monitored.
- The set pressure of the safety valve must be checked periodically.
- The air-fuel ratio must remain stable.
- When starting the boiler, the greatest precautions must be taken.
- The color of the flame should be checked periodically.

- The treated water must be used as the boiler feed water.
- The equipment must be maintained periodically.
- The pressure gauge must not be defective and must be followed a periodic calibration.

New Technologies for accident prevention

The technical-commercial magazine “*Calderas... Guía del Usuario (en la industria y comercio)*” Year 1, No. 2, says it is currently developing the Caldera 4.0, named for the fourth industrial revolution (also called the intelligent revolution). The equipment consists of modern combustion control, which allows us to be expanded in stages and in which the boiler controls are included, incorporating measurements, calculations, and alarms. This will result in a high availability and security benefit. Teams are increasingly automated, and some tasks depend little on people, so human errors are reduced. It is difficult for accidents to disappear in their entirety, however, technology offers us advantages to prevent them. *Combustión, Energía & Ambiente, S.A. (2020).*

Sustainable Maintenance Plan

The Government of Mexico recognizes that climate change represents the main global environmental challenge of this century and has been a leader among developing countries with its progressive goals, objectives, and regulatory actions at the national and international levels. *Climate Action Reserve. (2016).*

A sustainable maintenance plan successfully implemented can help improve the efficiency of a boiler, in addition to supporting the fight against global warming. *Behzad M. et al. (2018).*

Before making a sustainable maintenance plan, it is necessary to carry out a sustainability assessment (Figure 2), which is an appropriate method that simultaneously integrates the economic, social, environmental, and technical aspects of a system throughout its life cycle. *Sala, S. et al. (2015). & Santoyo, E. et al. (2014).*

Selection of Indicators and Criteria

There are several indicators and criteria to assess sustainability. However, not all indicators may apply to a particular topic. Indicators must have meaning in the study area and must be measurable, reliable, and easy to understand by stakeholders. Long, Y. et al. (2016).

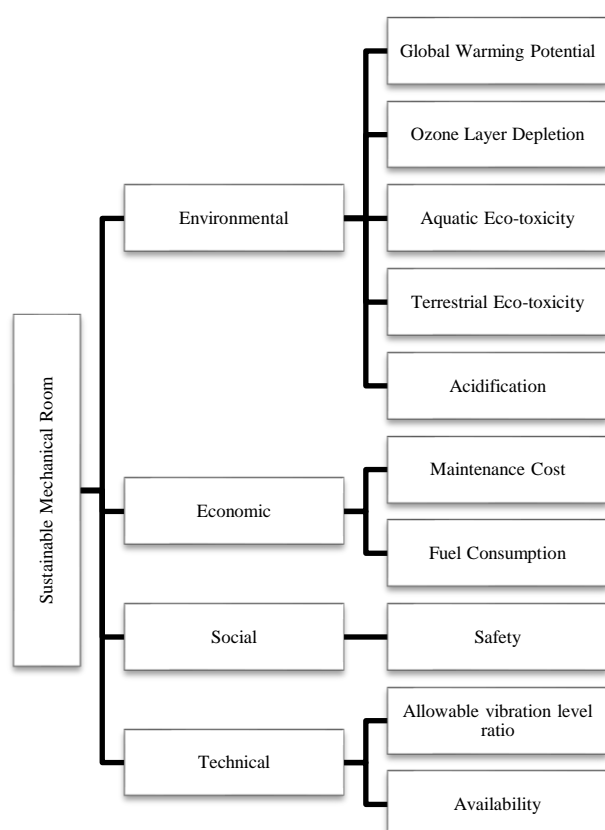


Figure 2 The general framework of indicators and criteria for evaluating sustainability

Source: Sala, S. et al. (2015). & Santoyo, E. et al. (2014)

Environmental Indicator

A boiler must comply with the established standards to avoid significantly damaging the environment because the energy inefficiency of the equipment can cause an additional amount of emissions of polluting substances such as Sulfur Dioxide (SO₂), Carbon Monoxide (CO), or Soot (C). Uribaz, P. et al. (2006).

Economic Indicator

In the economic indicator, two criteria must be considered, first, the cost of maintenance, which will depend on the company and the conditions in which it works. Second, the cost of fuel, in the case of boilers the best option is natural gas, which guarantees a cleaner ecosystem and lengthens the maintenance periods and useful life of this equipment, which also provides economic savings. Colás, J. (2005).

Social Indicator

In this indicator, social security stands out, to guarantee it, the established regulations must be complied with; In the case of Mexico, the Official Mexican Standard NOM-020-STPS-2011 indicates the safety conditions for the proper operation of pressure vessels. Personnel must be trained to carry out proper maintenance and this will ensure greater safety in the workplace. STPS. (2011).

Technical Indicator

The percentage of availability of the equipment is an indicator of the evaluation of the performance. Following formula (1) the availability of the system is obtained. Mobley, R.K. (2002).

$$Availability = \frac{Required\ Availability - Downtime}{Required\ Availability} \times 100 \quad (1)$$

Few sustainability evaluation studies introduce the vibration index as one of the indicators. In the case of vibrations in the boiler, these can be caused by several possible reasons, which can be divided between chemical and mechanical factors. Jasiński et al. (2016). & Mayyas et al. (2013).

Results

A study by Behzad, M. et al. conducted in 2018 investigated the impact of such a modern program on various parameters for forms of sustainability in a boiler room, using methods such as monitoring and predictive maintenance. The evaluation consisted of four criteria, such as environmental, economic, social, and technical. The improvement of the indicators led to a positive change in sustainability during the period of operation. It was shown that the program can be successful in improving the performance of all criteria, especially, the social and technical aspects. The results were also promising for the overall evaluation. Monitoring techniques and predictive maintenance led to an improvement of at least 28% in the sustainability performance of the boiler room during use. Masoud Behzad et al. (2018).

Discussion of results

According to the study by Behzad, M. et al. to implement a sustainable maintenance plan, based on social, environmental, technical, and economic aspects; it can be an alternative to increase the overall performance of the boilers, as well as to ensure the well-being of the personnel in the work centers. However, we should not underestimate other methods such as auditing to improve sustainability performance.

On the other hand, priority should be given to those methods that result in more improvement in the performance of the boiler, allow more safety, and reduce the emissions of polluting substances. Comparing these solutions could be a potential topic for further investigation. *Masoud Behzad et al. (2018)*.

Conclusions

Industrial safety is very important, but it has clear deficiencies in Mexico, and it is evident with the number of annual accidents (approximately 500,000 since 2008). Mexico was the Latin American country with the most registered boiler explosions (6 in total) in 2019, even so, there is no exact statistical data in the country on explosions or accidents related to pressure vessels, because the majority of the industries keep the referred data and are not reported, therefore the number of accidents is higher than indicated. *IMSS. (2019)*. & *Combustión, Energía & Ambiente, S.A. (2020)*.

Safety Standards such as the ASME code or the Official Mexican Standard NOM-020-STPS-2011 particularly cover the performance of exams and the awarding of certificates of competence to boiler assistants and engineers. However, these rules are often ignored or violated while being implemented at the grassroots level. The function of these laws is not simply to regulate commercial and industrial activity but to prevent accidents in the workplace. *STPS. (2011)*. & *Akshoy, P. et al. (2018)*.

To carry out full compliance with national and international standards, the user of the boiler must have qualified personnel to manage the equipment, carry out regular checks on it and carry out predictive maintenance programs. *Akshoy, P. et al. (2018)*.

An efficient way of working with boilers is through the implementation of sustainable maintenance, in which aspects such as environmental, economic, social, and technical impact must be considered. Operation and maintenance strategies help improve employee health and safety, protect the environment, and improve productivity. *Masoud Behzad et al. (2018)*.

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