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EFFICIENCY AND COMPLIANCE OF A STEAM BOILER WITH STANDARDS AND REGULATIONS

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Abstract- The risk associated with steam boilers comparing to other equipment and machinery is very important, and accidents are fatal when the conditions of use of such devices are not complying with current regulations. Global regulations attach a great importance to the minimum requirements applicable to steam boilers, these requirements cover all aspects starting from designing and manufacturing to commissioning, as well as periodic inspections and requalification. Furthermore, compliance with national or international standards as well as global regulations is under the responsibility of both manufacturer and boiler owner. The objective is to highlight any non-conformity or defects that could lead to unexpected damages or accidents. An efficient boiler is not synonym for a boiler conform to regulations, additional elements will be subject to control in order to certify that the boiler is completely safe and conform to applicable standards and regulations. We evaluated a steam boiler efficiency and assessed the conformity as per the international standards for efficiency assessment using indirect method to quantify heat losses. Non-conformities observed are related to absence of conformity document implying refusal of regulatory control, and non-conformity due to evacuation of combustion gas. Biggest heat losses are related to dry combustion gas (2.6%), loss by hydrogen combustion (2.2%), and loss by radiation (2.5%). Dry flue gas amount depends on the excess air amount that can be controlled and regulated to an optimal level by the mean of a combustion analyzer. Other actions will improve boiler efficiency such as, heat recovery using plate heat exchanger and insulation of boilers components where hot points are spotted with an IR camera that can be fixed in the boiler room to follow temperature variations.

Keywords: Boiler, Conformity Control, Standard, Regulation Diagnosis.

1. INTRODUCTION

In 2020, electricity production by thermal energy in Morocco represented 63% from total installed capacity in electricity production park of Moroccan National Office of Electricity and Water as shown in Table 1[1].

The Moroccan national vision of energy efficiency by 2030 plans to reduce national energy consumption from 22% to 17% through a mandatory energy audit for Moroccan companies, and energy efficiency measures requiring relatively low-cost investments or actions to be undertaken.

Table 1. Total electrical production by thermal energy in Morocco

Energy source	Installed capacity in MW
Coal (including JLEC)	4116
Gas turbine power plants	1110
Combined cycles	834
Thermal Diesel	314
Fuel oil	300
Total thermal energy	6 674

Although Morocco is committed to diversify green sources of electricity production such as wind and solar energy, as well as establishment of new pumped energy transfer stations, a large part of the electricity is still produced by coal in Moroccan thermal power stations.

Industry represents an important part of Morocco's total energy consumption, and among the most energy-consuming sectors according to AMEE (Moroccan Agency for Energy Efficiency) the Agri-food industry, the textile industry, the mining sector, and metal processing. Steam boilers, widely deployed in Moroccan energy-intensive industry as well as in light energy-consuming industry, are used to meet the needs of companies for steam used for manufacturing and production processes [2, 3].

In the industrial sector, the most common boilers are fire tube boilers powered by solid, liquid, or gaseous fuel. Several Moroccan companies have turned to upgrading their boilers to face economic and environmental challenges as well as to strengthen their competitiveness, either by restoring boilers already in place or by installing new boilers that comply with international standards and Moroccan regulations.

2. INTERNATIONAL NORMATIVE REQUIREMENTS AND GUIDELINES FOR STEAM BOILERS

In Europe, high and low pressure steam boilers are manufactured in accordance with the pressure equipment directives "97/23/EU and 2014/68/EU", with the German technical regulations for steam boilers "TRD" and possibly with the technical standards "AD 2000 Merkblatt" [4]. In United States of America, or Canada, steam boilers should comply with ASME code for steam generators and pressure to promote the marketing on national and global level. This code not only ensures compliance with national standards, but also ensures that the equipment is secure and meets safety requirements set out by specific international directives and regulations.

In some countries around the world there are technical regulations and national standards that manufacturers must comply with when manufacturing steam boilers, such as the Indian boiler regulation (IBR), G.N.A. 101 of 1962 in China, as well as PD 5500 code and standard EN 13445 for United Kingdom. Currently, international regulations require a conformity assessment, which covers the design and manufacture of steam appliances before entering the market. This assessment is carried out by organizations authorized and approved by the state, and it results in a conformity marking such as CE marking for the EU and UL or ASME marking for United States of America.

3. COMPLIANCE OF STEAM BOILERS WITH EUROPEAN STANDARDS AND REGULATIONS

EU 97/23 directive and its successor 2014/68/EU [5, 6]requires that every steam boiler must undergo a conformity assessment before entering the market, which ensure below requirements:

• The boiler's compliance with harmonized European standards in terms of design, manufacture, and testing.
• "CE mark" with a declaration of conformity "DoC"
• Conformity document to be provided by manufacturer for inspection purposes.

Documentary control concerns documentation that supplier should provide, and which includes design and manufacturing plans and component diagrams, user guide, list of applicable standards and regulations, test reports, declaration of conformity.

Directive 2014/68/EU proclaims as conform any pressure equipment complying with national standards transposing harmonized norms, as well as devices marked "CE" and provided with "CE DoC". Harmonized standards in force are EN12952 and EN12953.

Conformity assessment procedure stipulated by directive 2014/68/EU reports 12 modules implemented according to the category in which the device is classified as established in article 13 of the directive. This evaluation procedure is linked not only to the type of boiler, but also to the temperature and pressure of the steam. It can be limited to internal production control, or extended to full quality assurance with design control, including EU type examination, product verification and supervised equipment control.

4. MOROCCAN REGULATION ON STEAM BOILERS

In Morocco, construction, maintenance and commissioning of steam boilers are regulated by the Decree of August 19, 1953[7], which sets below requirements:

• Materials used in construction and repair of steam boiler
• Essential safety devices
• Location conditions for a steam boiler.

The commissioning and use of steam generators in Morocco are governed by the Dahir of July 22, 1953 (9 Kaada 1372)[8] related to land-based steam appliances. This Dahir stipulates that before commissioning of a steam boiler, a declaration must be sent by the user to the competent authority services (mining department) and that the device must be subject to a visit and test so as to verify the security conditions of his employment.

A hydraulic test is carried out on each boiler to observe any type of leak or permanent deformation, and it is supervised by a mining service engineer or a delegate from an organization among the 30 organizations approved by the director of industrial production and mines in Morocco. The Dahir also obliges users to conduct a complete inspection of the steam apparatus at least every year to guarantee operation in the best safety conditions.

As part of the reform of regulations governing steam appliances, the Ministry of Energy Transition and Sustainable Development in Morocco has launched a project to develop and implement a computer application for monitoring activities relating to steam boilers. The objective being to establish an updated database of steam appliances and users (legal or natural persons), of approved control bodies and agents employed by these bodies as well as exemptions granted by the Ministry [2]. This project will help authorities to maintain a good quality control and a proactive intervention to deal with boilers non-conformity and associated risks.

5. PERIODIC INSPECTION AND CONTROL OF A STEAM BOILER

The inspection of pressure equipment and piping is an important tool of regulatory control that helps prevent risks and keep the equipment in a good working order. In Europe, the procedures for monitoring steam boilers in service are included in the decree of November 20, 2017, which requires that all pressure equipment shall be inspected every 2 years. The inspection includes an external and internal check of the equipment according to the size and operating pressure of the equipment. This periodic inspection includes non-destructive testing, verification of safety accessories and pressure resistance test, as well as verification of the documentation. Beyond the periodic inspection, the regulation require a periodic requalification (every 10 years) which may include an hydraulic test on the equipment [9].

Some European countries adopted a monitoring policy based on prescriptive regulations that define the obligations and flexibility granted to industrial companies, while other countries have opted for objective-based regulations that reframe general requirements and transfer responsibility for the management of equipment to industrial companies [9].

In general, regulations require the operator of a steam generator to draw up an inspection plan, which must be approved by an authorized control organization, and which defines the monitoring actions to ensure a complete examination of steam boiler, from commissioning and throughout periodic requalification [10]. Article 13-IV from ministerial decree of 20 November 2017 specifies that "inspection plan is established according to professional guides or approved professional technical specifications (CTP), or according to other guides or CTP approved by decision of Minister in charge of industrial security "[11].

A study carried out by the Pressure Equipment Observatory [12, 13] reports a drop in the number of inspections and periodic requalification on steam boilers from 18 to 44%. This is due to application of Ministerial decree of November 20, 2017, which extended certain inspection intervals, and which has a structural impact on steam boilers compliance inspection.

6. STEAM BOILER CONFORMITY VERIFICATION AS PER MOROCCAN REGULATION

Regulatory control in application of Dahir 12/01/1955 and Dahir of 07/22/1953 (CHANCEL, 1963; GUILLAUME, 1953) set up requirement to be respected by authorized control organizations during periodic inspection and conformity assessment who should follow the steps.

6.1. Equipment Identification

Conformity verification of identity marks and plate fixed on the equipment (by rivets or other means):
• Manufacturer's name, place, year, and construction number;
• Presence of the hallmark of an organization approved by the Ministry of Energy and Mines;
• Stamp pressure and date of proofs (stamp medal).

6.2. Administrative and Regulatory Verification

Equipment in service must be declared to the regional service (steam equipment). The boiler operator should provide technical and administrative documents such us: test certificate, inspection report, maintenance register...

6.3. Regulatory Visit

• Verification of identity marks (stamp of anorganization approved by the Ministry of Energy and Mines)
• Verification of correct operation and physical condition of the device
• Functional test of security organs
• Obvious non-conformities and defects to be reported on inspection reports
• Verification of boiler's maintenance log.

6.4. Internal and External Review

The objective is to detect faults and possible repairs to assess their seriousness. The check is carried out on the stationary equipment isolated, opened, and cleaned.

6.5. Hydraulic Test

The fluid used to perform hydraulic test is generally water, or in some cases it may be necessary to use treated water (demineralized, degassed, chlorine-free). The pressurization, at least as regards the passage from the design pressure or the maximum effective pressure to the test pressure, is carried out slowly and gradually in the presence of an expert.

7. CONFORMITY ASSESSMENT AND NONCONFORMITIES OF STEAM BOILERS

Steam boilers consume a significant amount of energy to generate steam for industrial field as shown in Table 2.

Table 2. Energy used to generate steam in several industries [14]

Industry	Energy to generate steam (PJ)	% of total energy used by this industry
Paper and pulp	2 318	83%
Chemical products	1 957	57%
Oil refining	1 449	42%

Regulations consider steam boilers as high-risk equipment. Risks generated by poor maintenance and non-compliance of steam boilers are several and can be fatal, this may result in [15]:
• Equipment explosion;
• Splash projection in case of breakage;
• Loss of equipment containment capacity (toxic or flammable gas leaks).

The main modes of degradation of metallic materials in a steam boiler are various:
• Wet corrosion: generalized, galvanic, localized, or other type;
• High temperature corrosion: caused by gases and liquids, molten salts, or by liquid metals;
• Mechanical and physical degradation of materials linked to mechanical or metallurgical factors.

The effect of above degradation modes varies following the cause, and it can generate cracks, loss of thickness, ruptures, denaturation, or embrittlement of the steam boiler's material.

During periodic inspections of a steam boiler, various non-conformities (NC) can be noted. These non-conformities can be visible and obvious to the inspector, and sometimes they require a specific diagnosis or tests. The non-conformities are recorded on the report which is drawn up by the inspector and which is given to the boiler operator to proceed for corrections. In the industrial sector, experts highlight following major non-conformities raised during commissioning control or periodic inspection or requalification [12]:
• Non-compliance due to safety accessories
• Non-conformity due to pressurized accessories
• Non-compliance associated to boiler wall
• Non-compliance associated to boiler tests
• Non-compliance with administrative rules

Data shared by an authorized control organization concerning non-conformities noted during steam boilers conformity assessments, shows that recurrent non-conformities are related to accessories under pressure, and to boilers wall and non-compliance with administrative rules as shown in Table 3. These non-conformities led to rejection of commissioning controls, inspections, and periodic requalification, to which the industrial companies controlled, had to remedy to obtain the requested certification. The rejection rate is shown in Figure 1.

Table 3. Non-conformities reported on a steam boiler

Non-conformity type	Commissioning control	Periodic requalification	Periodic inspection
Safety accessories	0	9.9%	28.2%
Pressurized accessories	20%	1.2%	0.4%
Boiler wall	0	44.4%	38.7%
Boiler tests	0	37%	0%
Administrative Rules	80%	7.4%	32.7%

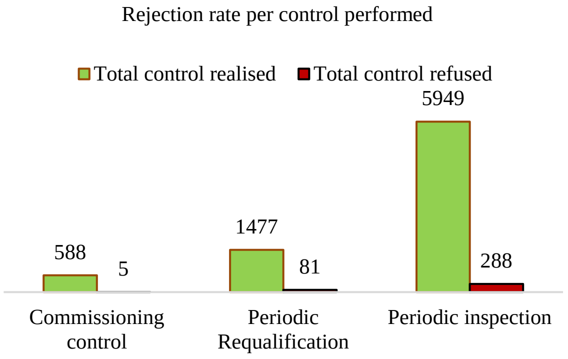

Figure 1. Total refusals due to boiler non-compliance

8. EFFICIENCY AND CONFORMITY ASSESSMENT OF A STEAM BOILER

To calculate efficiency of a fire tube steam boiler, we used the indirect method. The main goal is to identify the major heat loss occurring at different level of the boiler system. We considered the below losses as the international standards for boiler efficiency assessment (IS, BS):

• Dry combustion gas loss (p_1):

$$p_1 = \frac{m_g \times C_g p \times \left(T_g - T_a\right)}{HHV} \times 100 \quad (1)$$

• Loss by hydrogen in combustible (p_2):

$$p_2 = \frac{9 \times h \times [584 + C_v p \times \left(T_g - T_a\right)]}{HHV} \times 100 \quad (2)$$

• Loss by humidity in combustible (p_3):

$$p_3 = \frac{m \times [584 + C_v p \times \left(T_g - T_a\right)]}{HHV} \times 100 \quad (3)$$

• Loss by humidity in air supplied for combustion (p_4):

$$p_4 = \frac{a \times M_f \times C_v p \times \left(T_g - T_a\right)}{HHV} \quad (4)$$

• Loss due to incomplete combustion (p_5):

$$p_5 = \frac{C' \times C \times 5744}{HHV \times (C'' + C')} \times 100 \quad (5)$$

• Radiation and convection loss (p_6):

$$p_6 = 0.5 \times [(\frac{T_S}{55.5})^4 \times (\frac{T_a}{55.5})^4] + 1.9 \times \times (T_S - T_a)^{1.2} \times \sqrt{\frac{196.8 \times v + 68.9}{68.9}} \quad (6)$$

Using data collected during a measurement campaign as reported in Table 4 in Appendix (combustible quantity and analysis, combustion gas analysis, etc.). We obtained an efficiency of 91.6% (Figure 2) close to nominal efficiency reference. Biggest loss as highlighted on figure 3 are loss by dry gases with 2.6% which varies according to combustible, to air supplied for combustion and to combustion gas temperature. Boiler efficiency is considerably affected by combustion gases which carry away an important part of energy, so this loss can be reduced if an optimal amount of air is supplied to obtain a stoichiometric combustion. Loss due to radiation is around 2.5%, and it can be considerably limited if boiler and its components (pipes, valves, etc.) are insulated, and if insulator thickness is optimal taking into consideration heat loss and insulation cost [16]. Loss by water formed in combustion products is also important and it represents 2.2% of total heat loss, whereas heat is lost as vapor carrying away energy depending on temperature and pressure conditions, this loss can be recovered by a condensing heat exchanger.

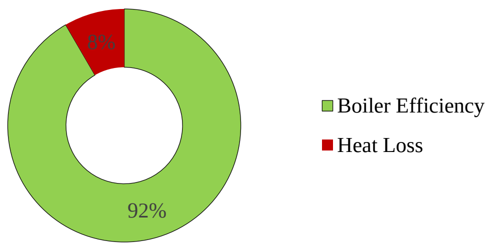

Figure 2. Steam boiler efficiency

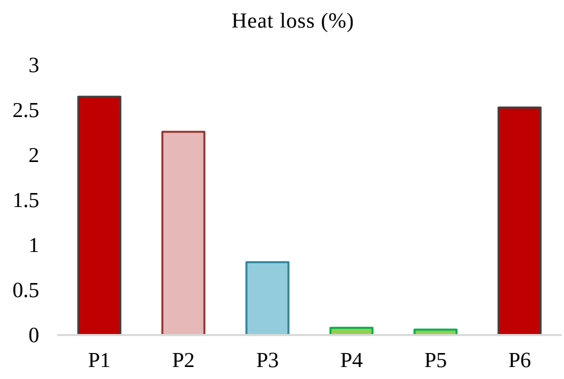

Figure 3. Steam boiler heat losses

9. CONCLUSION

Industrial sector is a large consumer of thermal energy produced by combustion. Steam is the heat transfer fluid of choice for its advantages over other heat transfer fluids, and it is produced mainly by steam boilers. Pressure equipment is considered by global regulations as high-risk equipment, which must be subject to normative control from designing to commissioning. Manufacturers must comply with standards and regulations applicable to steam boilers to be able to market their equipment in the global market, while equipment compliance before and during commissioning, is under boiler owner responsibility. Regulatory control is supervised by competent authority and is under responsibility of authorized control organization, and it covers documentary control and inspection of the boiler.

During inspection, any non-compliance observed must be reported to boiler owner who is responsible for corrective actions so the equipment can be used in safe conditions and so as to obtain periodic certification guaranteeing compliance with regulations in force. In the interests of environmental protection and sustainable development, some countries around the world are drawing up increasingly stringent regulations to limit the use of fossil fuels and pollution emitted by discharges and losses from steam boilers. Other countries are more tolerant on this subject and limit the requirements to safety of goods and people where environment and sustainable development is still not a priority or where regulations are old and not suited to the contemporary context.

Consequently, regulations should be updated more often to follow technological advances proposed by manufacturers, and the increasing demands of industries that continuously deploy boilers for different needs as well as to support energy transition in which Morocco is committed. We found that most recurrent non-conformity are related due to administrative rules, where some manufacturer does not provide necessary document to boiler owner, or where owner does not keep necessary documents for regulatory control purposes. Some immediate corrective actions can be undertaken by boilers owner to ensure a higher boiler efficiency (like insulation and adjustment of excess air to the optimal amount).

Finally, quality control improvement should start at boiler's owner level, by equipping the boilers chamber with essential tools for quick diagnosis and supervision (IR camera, flue gas tester...) and sharing the Return on Experience (ROX) with local authorities to participate in the ongoing regulatory reform.

APPENDIX

Table 4. Non-conformities reported on a steam boiler

Symbol	Description	Unit	Value
C	Carbon	%	35
h	Hydrogen	%	3.7
m	Moisture	%	12
C'	Carbon dioxide in exhaust gas	%	16.5
C''	Carbon monoxide in exhaust gas	%	0.05
m_g	Exhaust gas mass	kg/kg fuel	9.7
$C_g p$	Massic heat capacity of exhaust gas	Kcal/kg.°C	0.2
$C_v p$	Specific heat (Superheated steam)	Kcal/kg.°C	0.4
M_f	Factor (Moisture)	kg per kg of air	0.02
HHV	Higher heating value (combustible)	Kcal/kg	9350
T_a	Temperature (Environment)	°C	24
T_g	Temperature (Combustion gas)	°C	135
T_S	Temperature (Boiler surface)	°C	60
v	Wind Speed	M per s	0.4
a	Actual air supplied	%	8.7
p_1	Formula 1	%	2.6
p_2	Formula 2	%	2.2
p_3	Formula 3	%	0.8
p_4	Formula 4	%	0.08
p_5	Formula 5	%	0.06
p_6	Formula 6	%	2.5
η	$=100-\sum p_i$	%	91.6

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BIOGRAPHIES

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