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STEAM BOILERS IN READY-MADE GARMENTS INDUSTRY IN BANGLADESH: EXISTING SCENARIO AND SCOPE FOR DEVELOPMENT

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ABSTRACT

Bangladesh's Ready-Made Garments (RMG) industry, historically prone to hazards including boiler explosions with numerous fatalities, has prompted the RMG Sustainability Council (RSC) to initiate boiler safety inspections. This study addresses the lack of empirical data on boiler operations in RMG factories, focusing on operational scenarios, risk factors, and remediation strategies. Conducted from March 2021 to March 2023, structured visual inspections across 1386 RMG factories assessed 2204 boilers. Key findings reveal that 34.99% of factories predominantly use a single boiler, 91.24% of boilers are government-registered, and the majority are imported (63.29%) with a steam generation capacity below 1,000 kg/hr (59.75%). Additionally, 63.11% were manufactured between 2010 and 2019, 79.63% burn fossil fuels, 54.60% are vertically oriented, and 82% use softened feedwater. The study also identifies 32 external risk factors across 11 categories, providing insights for decision-makers to enhance boiler operation safety and sustainability. By leveraging this inspection data, the research aims to bridge the empirical gap and offer a comprehensive understanding of the existing challenges in RMG boiler operations.

Keywords: *Boiler Safety; Ready-Made Garments Industry; Visual Inspection, Risk Factor, Remediation.*

1. INTRODUCTION

The boiler is an indispensable electro-mechanical device that is installed by most RMG factories for drying and ironing clothes using steam (Rahman *et al.*, 2022). Being one of the major apparel manufacturing nations in the world, Bangladesh is industrialized with thousands of RMG factories, and millions of people are involved in this emerging industry (Chowdhury *et al.*, 2023). A huge number of boilers of different variations based on their type, size, manufacturing year, fuel, and country of origin are engaged in the regular operational process of these factories. According to the office of the Chief Inspector of Boilers (CIoB) which is the only legislative authority for boiler operation by the government of Bangladesh, there are 7399 registered boilers in the country in 2022 (Boiler and Boiler Operator Statistics, 2022). A major portion of those boilers is used by the RMG sector (Ali and Habibullah, 2019). However, no procedural industry-based data analysis on industrial boilers in Bangladesh is observed to assist the local and international policymakers. The limited organizational structure to gather industrial data by visiting factories in scattered locations is the primary reason behind this. This profound gap in the literature is worthy of mitigating. Therefore, this work is going to depict a descriptive statistical presentation of the gathered data on 2204 boilers from 1386 RMG factories in Bangladesh.

In addition to this, the risk factors which are found very frequently in external visual inspections of industrial boilers in Bangladesh are going to be discussed with standardized remediation suggestions. These data have been collected by the visual inspections conducted by the RMG Sustainability Council (RSC), a regulatory private organization for ensuring sustainable workplace safety in the RMG factories in the country.

RSC is a tripartite initiative incorporated by the industry, global fashion brands, and trade unions to inspect, suggest remediation, monitor, and follow up on the RMG factories to deliver world-class safety and sustainability since June 2020 (RSC, 2021). As it is a continuation of the programs run by the Accord (the Accord on fire and building safety in Bangladesh), RSC has been continuing the boiler safety program initiated by the Accord as a pilot program in 2018.

Despite being a major exporter of RMG, workplace safety has always been neglected in this emerging industry of Bangladesh consisting of over 4 million people working in more than 4500 factories (Siraj *et al.*, 2022). Hence, this industry faced several deadly incidents like fire incidents, electrical accidents, structural collapse, and boiler explosions throughout its journey (Hasan *et al*., 2017, Siraj *et al.*, 2022). Several research works have been carried out to demonstrate the solution to industrial accidents in RMG factories in Bangladesh. However, there is a lack of empirical data on boiler operation gathered from factory inspections (Rahman *et al.*, 2022). For instance, Rahman *et al.* (2022) modelled the causes of boiler accidents in RMG factories utilizing the experts'

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opinions. But they had no scope to visit the factories to verify the practical industrial scenarios, rather they conducted a theoretical analysis. Hossan *et al.* (2019) did a qualitative study to describe the causes, consequences, and precautions for boiler explosions in the RMG factories. Wiersma (2018) and Barua and Ansary (2017) both depicted in their descriptive studies the improvement in fire safety scenarios in the RMG factories after the safety inspection initiated by the Accord. They indicated boiler accidents as a reason for the fire. Similarly, Hasan *et al.* (2017) analysed the previous accidents in the RMG factories in which some boiler accidents were severe. However, those descriptive studies could not mitigate the gap in the literature by providing a relevant analysis of the existing boilers' conditions of the RMG factories.

With a heat transfer calculation, Saha *et al.* (2021) determined a major source of heat loss in the steam generation process in a boiler, which is dry flue gas. According to their study, a heat recovery system can be effective to minimize heat energy loss in RMG factories. Roushan (2021) showed the utilization of waste fabric from RMG factories as a fuel for a boiler can minimize the use of fossil fuels, thus helping to achieve environmental sustainability. The benefits and feasibility of these works can only be analysed on a large scale if there is adequate statistical information on the categories of the existing boilers in the RMG factories.

Utilizing descriptive statistics, Paul and Alam (2018), as well as Paul *et al.* (2020), analysed the boiler safety scenarios in South Asian countries including Bangladesh. They depicted the scope of authoritative inspections for boilers as limited and demonstrate that as a major reason for boiler accidents in Bangladesh. Ali and Habibullah (2019) discussed the organograms and the existing laws of the enforcing body for boiler operations, that is CIoB in Bangladesh, as well as analysed previous boiler accidents in a descriptive statistical approach. Those statistical studies revealed the necessity for a detailed statistical analysis of the boilers in the RMG factories of Bangladesh to get remarkable insight.

The above description shows the absence of an in-depth study conducted by inspecting RMG factories. Moreover, visual inspection data analysis can assist industrial policymakers to be benefiting from the previous theoretical studies on boilers in the RMG industry. Amid this situation, this study is going to contribute to the literature by fulfilling the following objectives-

a) To present the largest dataset from external inspections of RMG industry steam boilers in Bangladesh.
b) To categorize RMG steam boilers based on data analysis to understand current usage trends.
c) To identify key risk factors in RMG steam boiler operations.
d) To propose risk mitigation strategies based on local and international standards.

The rest of the paper is organized as follows: Section 2 discusses the theoretical basics of boiler classification, components, and legislation in Bangladesh. Section 3 conceptualizes the background of initiating visual inspections of boilers by the RSC. Section 4 details the inspection procedures and data collection methods. Section 5 categorizes the boilers using various parameters from the gathered data. Section 6 examines existing risk factors and suggests remediations for boiler operations. The implications of the study outcomes are described in Section 7. Finally, Section 8 concludes the paper, discussing unique results, the study's limitations, and future research possibilities on boiler operations in Bangladesh.

2. BOILERS: CLASSIFICATION, COMPONENTS, AND LEGISLATIONS IN BANGLADESH

Using steam for drying purposes in industries was introduced in the mid of the 19th century (Wimmerstedt, 1995). However, steam boilers started to get their present structure long before that, in the 17th century (Teir, 2002; Riznic, 2017). Steam boilers can be said to be thermal devices that generate steam from the water in a pressure vessel utilizing heat energy. For the last few decades, the operations, maintenance strategies, and safety of steam boilers have been developed through continuous research to meet industrial requirements (Teir, 2002; Patil *et al.*, 2022). Steam boilers can be classified with various parameters or categories. According to Teir (2002), Annaratone (2008), and other studies, the classification of modern steam boilers is depicted below-

Based on heat source: Solid fuel (coal, wood, waste fiber, etc.), liquid fuel (diesel, heavy fuel oil, liquified gas, etc.), gas, electricity, and waste heat from other devices.

Based on heat transfer: Convection, radiation, or indirect heating.

Based on circulation: Natural circulating, assisted circulating, and forced-circulating.

Based on the ratio of water content and heating surface: High water content (50~100 kg for 1 square meter), medium water content (20~50 kg for 1 square meter), and small water content (below 20 kg for 1 square meter).

Based on the fluid passage: Water-tube and fire-tube.

Based on physical orientation: Horizontal, vertical, and inclined.

Based on working pressure: High pressure (equal or above 80 bar) and low pressure (below 80 bar).

Some main components of steam boilers (Vandagriff, 2001; Heselton, 2020) can be mentioned below-

Feed Water Pump: To feed or supply water into the boiler, this pump is used.

Burner: Air and fuel are mixed in a burner to combust. Maintaining a perfect air-fuel ratio is important for efficient and clean combustion.

Combustion Chamber: This chamber is a place where fuel is burnt to heat the water for steam generation. Heavy-duty metals are used to build this chamber to cope with several hundred degrees Celsius temperatures.

Heat Exchanger: Heat from the burner and the combustion chamber is exchanged through this component. This may be made up of a bundle of heavy-duty metal tubes, or wire. The overall performance efficiency of a boiler highly depends on the efficiency of the heat exchanger.

Controlling Systems: Modern days boilers are controlled by electrical control devices to control temperature, air-fuel mixing ratio, pressure, etc.

Steam Lines: These are pipes that carry water to the boiler and supply produced steam to consuming points.

Exhaust Stack: This component is similar to the chimney which carries burnt gases or exhaust gases from the boiler to the external environment.

Boiler Mountings: These refer to some components of the operational efficiency and safety of a boiler, such as water level indicators, pressure gauges, safety valves or pressure relief valves, steam stop valves, blow-off valves, feed check valves, and so on.

Boiler Accessories: These refer to some components that can increase the performance efficiency of a boiler, such as air pre-heater, superheater, economizer, steam separator, and so on.

According to Boiler Use and Inspection Guide (2020), an overview of the legislative and standard requirements of boiler operations and maintenance in Bangladesh can be described below-

Boiler Import: Boiler manufacturing drawings, material design particulars, and boiler construction designs must be submitted to the CIoB and approved by the CIoB before import.

Boiler Registration: To operate a steam boiler in Bangladesh, the boiler must be registered and permitted by the CIoB whether it is imported or locally manufactured. All registered boilers will be provided with a registration number which needs to be engraved on a nameplate and be visible during the inspections.

Registration Renewal: Registration of all registered boilers must be renewed by the CIoB every year after checking the competency of the boilers by an authorized boiler inspector.

Boiler Operator: The operators of the registered boilers must be certified by the CIoB.

Water Softening: Boiler feed water must be softened, keeping the pH level between 7 to 9, the hardness between 0 to 5 ppm, and the TDS maximum 250 ppm.

Operation and Maintenance Log sheet: A log sheet should be maintained for regular monitoring of boiler performance and maintenance updates.

Modification of Boiler's s Pressure Parts: Permission and consultation must be taken from the CIoB before modifying any pressure parts of the boilers.

Operating Pressure: Boiler's operating pressure must be limited within the maximum allowable working pressure permitted by the CIoB.

Details of legislative guidelines regarding boiler operations can be found in Boiler Law-2022 (Laws of Bangladesh, 2022).

3. CONCEPTUALIZING THE BACKGROUND OF BOILER INSPECTION IN RMG INDUSTRY

Industrial safety practices of the ready-made garment (RMG) factories of Bangladesh have improved to a greater extent after initiation of regular safety inspections by the Accord in 2013 (Ahlquist and Mosley, 2021). The workplace safety environment at the RMG factories was devastating before that (Barua and Ansary, 2017). The RMG industry is the major revenue-earning sector for this emerging economic country for the last few decades. However, several deadly incidents caused by non-standard practices and negligence throughout these years challenged the sustainable progress of the industry and affected workplace safety (Hasan *et al.*, 2017). For instance, the fire incident at the Tazreen Fashion in 2012 and the building collapse of Rana Plaza in 2013 can be

mentioned here as two of the most lethal tragedies in industrial history. That fire incident caused 112 deaths, whereas the building collapse was even worse, which caused more than a thousand deaths and two thousand injuries (Reinecke and Donaghey, 2015; Sumon *et al.*, 2017). The national and international policymakers as well as the global community did nothing but showed their immediate concern after those tragic incidents and the Accord was formed in 2013 to inspect fire and building safety issues of RMG factories in Bangladesh (Ahlquist and Mosley, 2021).

Fire, electrical and structural hazards were significantly minimized at more than 1600 Accord-listed RMG factories by continuous inspection, monitoring, and remediation suggestion by the Accord (Barua and Ansary, 2017; Wiersma, 2018). However, the death of 13 workers and several injuries due to a severe explosion of a boiler at Multifabs Clothing Factory in 2017 revealed a gap in the Accord inspection scope ("Boiler explosion", 2017). Studies disclosed that boiler operations are associated with several critical hazards such as explosions, steam burns, chemical hazards, and so on which cannot be covered in a fire or electrical safety inspection scope (Hossan *et al.*, 2019; Siraj *et al.*, 2022; Yusof and Mohammad, 2022). Therefore, the Accord planned to initiate a boiler safety inspection department separately in 2018 to minimize boiler-related hazards in the RMG factories and conducted a pilot inspection program for 35 boilers in 17 factories (Accord, 2019). That pilot program had several critical findings such as the absence of water treatment facilities, boiling water and steam leakage, improper maintenance activity, leakage on the fuel line, improper insulation, faulty electrical wiring in the boiler panel, and so on. Figure 1 is presenting some of the critical risk factors observed in the Accord's boiler safety pilot program.

Figure 1: Corrosion of the metal and scale formation inside the boiler for using untreated water (Accord, 2019; Siraj *et al*., 2023)

Those findings from the Accord's pilot program indicated the necessity of expansion of the boiler safety program all over the RMG factories. However, some legal issues hindered the full-phase implementation of the boiler safety program, as the agreement of the Accord in Bangladesh came to an end on May 2020 (Munni, 2019). The RSC was formed with all the organizational infrastructure of the Accord in June 2020, which is known as the Accord-RSC transition. Within the years 2018 to 2020, more boiler explosions in the RMG factories enforce to accelerate the boiler safety programs by the RSC. Figure 2 is showing pictorial evidence of two devastating boiler explosions in the RMG factories within the last few years.

A common stereotype was established among the factory owners that, only large boilers could explode, and mini-boilers were safe. Even the Boiler Law-2022 by the government of Bangladesh supported this stereotype by declaring that steam generators whose water storage capacity is less than 25 liters are not boilers (Laws of Bangladesh, 2022). Therefore, the office of the CIoB does not have any legal obligations to inspect such boilers. However, the explosion of such mini-boilers can also be devastating. For instance, an explosion of a mini-boiler took place in Sincere Composite Ltd at Narayanganj on January 19, 2021, and which incident was investigated by the RSC on January 21, 2021. Figure 3 is depicting the post-explosion severity at the factory.

The inspectors of the RSC found a non-compliance operational issue behind that explosion. They reported, the factory modified the level sensor of the boiler by increasing its length, which caused a dry-run of the boiler.

Moreover, the mechanical safety valve got stuck due to irregular maintenance and rust formation. Figure 4 is showing the investigated causes of the mini-boiler explosion at Sincere Composite Ltd.

Figure 2: Boiler explosion at Multifabs Ltd on July 3, 2017 (Left) ("Boiler explosion", 2017), and at Natural Sweater Village Ltd on December 10, 2019 (Right) ("One killed", 2019)

Figure 3: Mini-boiler (left), collapsed boiler room (middle), impact on the adjacent production floor (right); observed during the Incident inspection by the RSC at Sincere Composite Ltd.

Figure 4: Lengthening the level sensor by welding (left), rusted stuck safety valve (right); observed during the Incident inspection by the RSC at Sincere Composite Ltd.

There are a lot of mini-boilers operated in the RMG factories in Bangladesh which are not defined as a boiler in the Boiler Law-2022. Against this backdrop, , the RSC started to implement the boiler safety inspection program on March 2021 to ensure the standard practices for boiler operation in the RMG factories of Bangladesh to support its ongoing journey towards sustainability.

4. METHODS OF THE VISUAL INSPECTION AND DATA COLLECTION

The boiler safety program by the RSC has three phases. The first phase is to visually inspect the boilers and boiler rooms of the factories, the second phase is to internally inspect the boilers and conduct a hydrostatic pressure test, and the third phase is to test the functionality of the boilers. This ongoing study is confined to only analyzing the data gathered from the visual inspection. This phase is necessary to get an overview of the boiler

operations in the RMG factories, determine the most frequently observed risk factors in boiler operations, prioritize the most risk-prone boilers and the factories, and prepare detailed guidelines for boiler operation in the Bangladeshi industrial perspective.

The visual inspections were conducted between March 2021 to March 2023. Within this timeframe, 9 inspectors visually inspect 2204 boilers from 1386 RMG factories at different locations in the country. All those inspectors were either mechanical engineers or electrical engineers. They were trained by the TÜV SÜD, a Germany-based world-renowned company to inspect, test, and certify mechanical accessories. Table 1 is presenting an overview of the visual inspections and the inspectors.

Table 1: An overview of the visual inspections and the inspectors

Inspections			Inspectors		
Inspection time frame	Number of factories	Number of boilers	Number of inspectors	Educational qualifications	Inspection qualifications
March 2021 to March 2023	1386	2204	9	7 mechanical engineers, 2 electrical engineers	Trained up by the TÜV SÜD, Munich, Germany

Before initiation of the physical inspection, RSC enlisted 1724 factories that were surveyed via Google Forms. The survey was conducted to have some general information about the number of the boiler, fuel, manufacturing year, registration year, water treatment facility, steam generation capacity, etc. This survey was important to do the inspection schedule by the RSC. According to the location of the factory attained from Google Maps, 1 inspector was assigned to conduct the visual inspection of the 2 factories located close to each other in a day. Among 1724 factories, 90% factory responded to the survey questionnaire. The survey responding status can be found in table 2.

Table 2: Summary of the online survey response

Category of the factories	Number of factories
Factories using boilers	1386
Factories using no boiler	170
Factories yet to respond to the online survey	168

RMG factories in different districts of the country were covered by these visual inspections. The methodology of inspections, data collection, and reporting steps are depicted in figure 5.

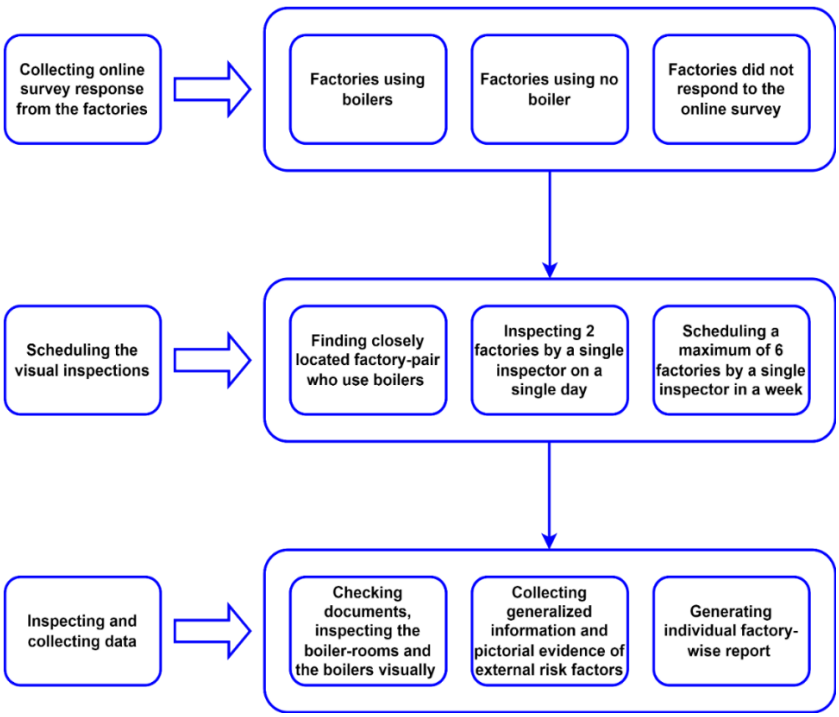

Figure 5: The procedural steps of the visual inspections by the RSC

During the visual inspections of the boilers, the RSC engineers checked some necessary documents first, then physically visited the boiler rooms to inspect the boilers. Table 3 presents the activities of an engineer in a visual inspection.

Table 3: Activities during inspections

Name of the activity	Scope of the activity	
Documents checking	Legal documents	1. Boiler registration certificate 2. Boiler registration renewal certificate 3. Boiler operator's certificate 4. Not in scope certificate (applicable for mini boilers only)
	Technical documents	1. Boiler operation and maintenance manual 2. Boiler manufacturing drawings 3. Calculations for the parameters like heating surface, maximum allowable pressure, volume capacity, safety valves, etc. 4. Datasheets of mountings, accessories, and feed water pump 5. Boiler electrical wiring diagram 6. Boiler commissioning documents 7. Piping and Instrumentation diagram 8. Boiler operation and maintenance logbook 9. Flue gas analysis report (not applicable to electric boilers) 10. Water test report
Physical inspection	Boiler room	Ventilation, illumination level, clearance between the installed equipment, fuel, steam and water line, explosion relief area, fire-rated separation from other occupancies, egress obstruction, etc.
	Boiler	Boiler mountings and accessories, Boiler and steam lines insulation, maker's stamp of the boiler, boiler specification nameplate, other equipment nameplates (i.e., feed water pump, safety valve), etc.
External risk factors identification	Collecting pictorial evidence	Taking pictures of the overall boiler room, all identified discrepancies and risk factors with a digital camera.
	Discussions with the factory management	Informing factories about the identified risk factors and suggesting remediation for those risk factors.
	Report generation	Preparing individual reports for each of the inspected factories including the boiler data, observed risk factors with pictorial evidence, and remediation suggestions.

One of the major challenges in conducting these inspections in so many RMG factories was their scattered locations throughout the country. Table 4 is presenting the district-wise locations of the inspected factories.

Table 4: District-wise locations of the inspected factories

Districts	Number of Factories	% of total
Gazipur	626	45.17%
Dhaka	404	29.15%
Narayanganj	158	11.40%
Chattogram	111	8.01%
Mymensingh	50	3.61%
Cumilla	10	0.72%
Narsingdi	8	0.58%
Tangail	5	0.36%
Hobiganj	4	0.29%
Pabna	3	0.22%
Manikganj	2	0.14%
Sirajganj	2	0.14%
Bandarban	1	0.07%
Chandpur	1	0.07%
Jessore	1	0.07%
Total	1386	100%

The map of Bangladesh in figure 6 is depicting the visual inspection locations spreading in 15 districts of the country. These locations also indicate the major industrial hubs of the RMG factories are concentrated near Dhaka, the capital city of the country.

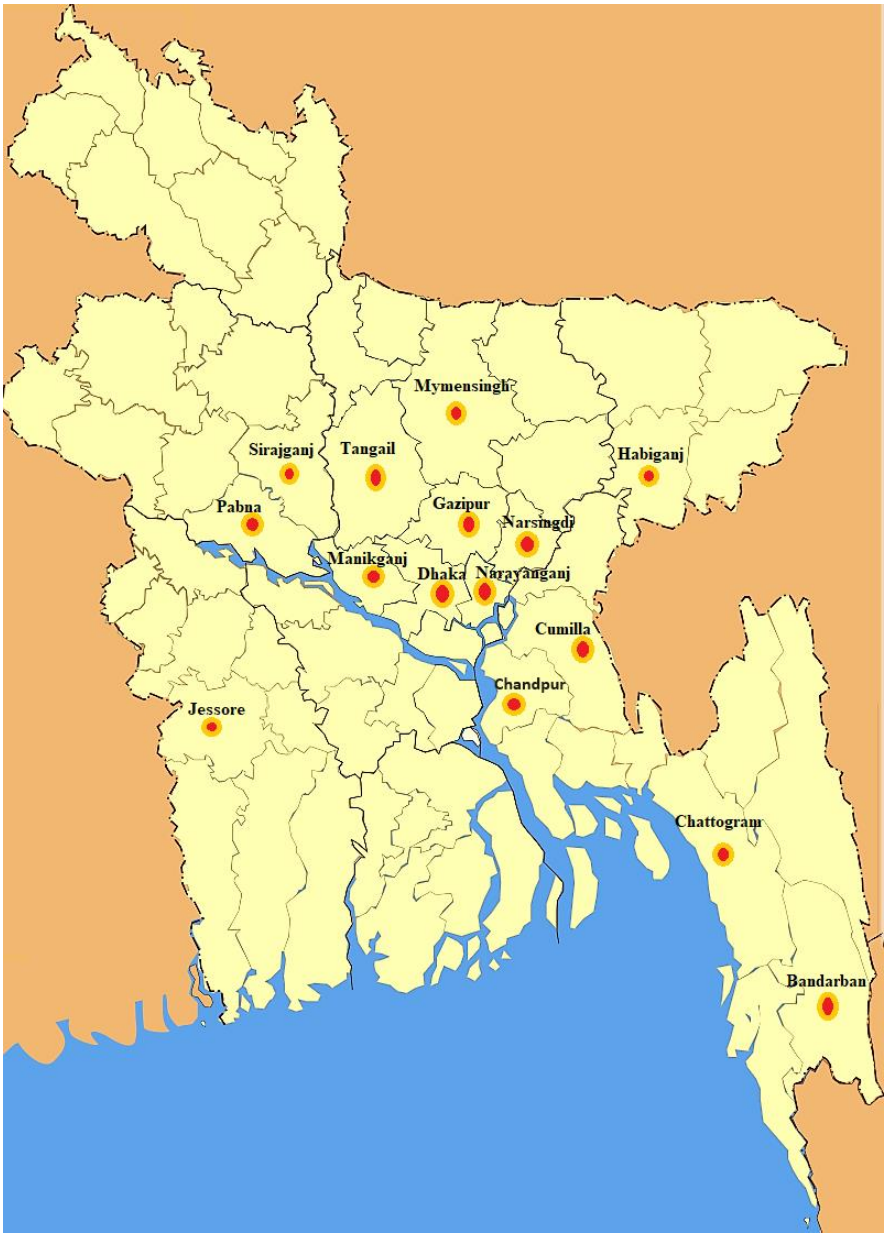

Figure 6: Locations of the inspected factories throughout the country

5. CATEGORIZING THE BOILERS BASED ON THE VISUAL INSPECTIONS

The gathered data has been analyzed utilizing descriptive statistical techniques. Factories select boilers of different categories based on the existing facilities and steam demand of their manufacturing processes. Some factories use multiple numbers of small or large boilers, whereas some factories use a single boiler. Table 5 is presenting an overview of the number of boilers used by the factories.

Table 5: Categorizing factories based on the number of boilers

Number of boilers	Number of factories	% of the total
1-boiler	485	34.99%
2-boilers	349	25.18%
3-boilers	242	17.46%
4-boilers or more	310	22.37%

Among the inspected 1386 factories, 485 factories use a single boiler, whereas the remaining 901 factories use multiple boilers. For descriptive statistical presentation, some variables of the boilers like the registration scenario, manufacturing year, country of origin, steam generation capacity, heat source, physical orientation, and the existence of water softener were considered.

5.1 Registration Scenario

Among the 2204 boilers visually inspected by the RSC, 2011 boilers were found with registration numbers, whereas, 35 boilers were found without registration. The remaining 158 boilers were mini-boilers for which government registration is not necessary, just a "not in registration scope" certification provided by the CIoB is required to operate. Table 6 is depicting the registration situations for the inspected boilers.

Table 6: Registration scenario of the inspected boilers

Category	Number of boilers	Percentage of the total
Registered	2011	91.24%
Non-registered	35	1.59%
Not in the registration scope	158	7.17%

5.2 Manufacturing Year

The visual inspection found the manufacturing years of the boilers with a wide range from 1966 to 2023. Therefore, the overall timeframe of the manufacturing years was segregated. In this segregation, the number of boilers manufactured before the year 2000 was 30, which is the minimum (1.36% of the total). Again, the number of boilers manufactured between 2010 to 2019 was 1391, which is the maximum (63.11% of the total). However, 226 boilers were found without any manufacturing documents. Therefore, the manufacturing years for those boilers could not be confirmed. Figure 7 is presenting the data for the manufactured years of the inspected boilers.

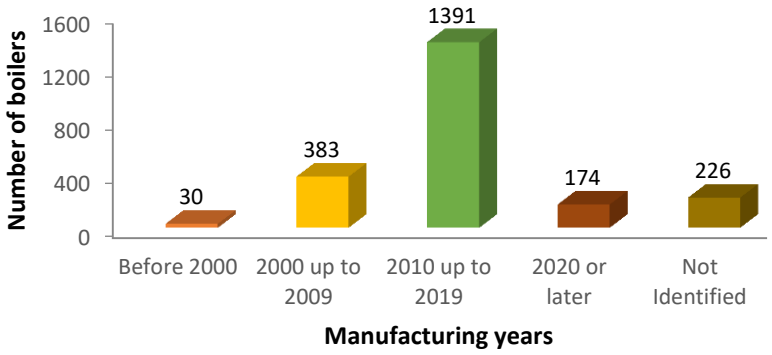

Figure 7: Manufacturing years of the inspected boilers

5.3 Country of Origin

Several boiler manufacturers like Modern Erection, Golden Boiler, SM Boiler, etc. are manufacturing boilers in Bangladesh (Hossan *et al.*, 2019). However, like all other equipment, a huge portion of the boilers used in Bangladesh are imported. Among the visually inspected 2204 boilers, 663 locally made boilers were found, whereas 1395 were imported. There were 146 boilers found for which the country of origin could not be identified. South Korea, the USA, India, China, and the UK are the leading countries from which boilers are imported. Table 7 is showing the information about manufacturing countries of the boilers.

5.4 Steam Generation Capacity of the Boilers

The steam generation capacity of the boilers was found within a large range. The minimum steam generation capacity was found to be 2.5 kg per hour, whereas the maximum steam generation capacity was found to be 16048 kg per hour. Segregating boiler steam generation capacities into several categories, Table 8 is presenting the number of boilers in each category. Among 2204 boilers, a total number of 1317 boilers' capacities were found to be below 1000 kg/hr.

Table 7: Country of origin for the boilers

Country	Number of boilers	% of the total
Bangladesh	663	30.08%
South Korea	263	11.93%
USA	233	10.57%
India	222	10.07%
China	188	8.53%
UK	143	6.49%
Japan	107	4.85%
Germany	85	3.86%
Taiwan	47	2.13%
Italy	36	1.63%
Indonesia	25	1.13%
Turkey	18	0.82%
Thailand	15	0.68%
Malaysia	6	0.27%
Scotland	3	0.14%
Australia	1	0.05%
Georgia	1	0.05%
Pakistan	1	0.05%
Romania	1	0.05%
Not Identified	146	6.62%

Table 8: Boilers based on steam generation

Steam generation (kg/hr)	Number of boilers	% of the total
Up to 250	306	13.88%
250 up to 500	700	31.76%
501 up to 1000	311	14.11%
1001 up to 2000	246	11.16%
2001 up to 3000	105	4.76%
3001 up to 4000	88	3.99%
4001 up to 5000	81	3.68%
5001 up to 6000	74	3.36%
6001 up to 7000	25	1.13%
7001 up to 8000	70	3.18%
8001 up to 9000	19	0.86%
9001 up to 10000	109	4.95%
10001 up to 11000	29	1.32%
11001 up to 12000	16	0.73%
More than 12001	25	1.13%

5.5 Heat Source

Boilers of the RMG factories are operated utilizing various types of heat sources such as fluid fossil fuel (natural gas, diesel), solid fossil fuel (coal), electricity, the waste heat of electricity generators (exhaust gas), solid waste fabric, etc. Therefore, boilers can be clustered by their heat source. Table 9 is presenting the categorization of the boilers based on their heat source. Among the visually inspected boilers, 1755 boilers were found to operate using fossil fuels which is 79.63% of the total boilers.

5.6 Physical Orientation

The physical orientation of the boilers was either horizontal or vertical. Space availability to install a boiler in a factory is an important factor to select which physical orientation can serve the purpose of the factory. In general, vertical boilers can save boiler room space and many factories which have space constraints prefer vertical boilers over horizontal boilers. 1203 boilers among the 2204 boilers were found as vertical, and the rest of the boilers were horizontal. Table 10 is presenting the categorization of the boilers based on their physical orientation.

Table 9: Boilers based on heat source

Heat source	Number of boilers	% of the total
Fossil fuel	1755	79.63%
Electricity	222	10.07%
Waste fabric	111	5.04%
Exhaust gas	116	5.26%

Table 10: Physical orientations

Physical orientation of the boiler	Number of the boilers	% of the total
Horizontal	1001	45.4%
Vertical	1203	54.6%

5.7 Water Softener

Though a water softener is a mandatory requirement for installing a boiler, many boilers in RMG factories were found to operate without any water softening arrangement. Furthermore, most of the mini boilers, which are not within the registration or inspection scope of the CIoB, were found to lack water softening facilities. Many registered boilers were also found using untreated groundwater as boiler feedwater. After completing a visual inspection of 2204 boilers, we found that 1813 boilers (82% of the total) were using softened water as feedwater, whereas the remaining 391 boilers (18% of the total) were found to be without water softening.

6. EXISTING RISK FACTORS AND REMEDIATION SUGGESTIONS

The external visual inspections conducted by the RSC have identified several critical risk factors in boiler operations that can lead to further damage and create workplace hazards, including the risk of boiler explosions. However, risk factors observed during an external visual inspection do not confirm the actual operable condition of a boiler. The operability can only be determined through an internal inspection, hydrostatic pressure test, and functionality test (Vandagriff, 2001; Sasaki *et al*., 2021).

Therefore, the risk factors identified in this study can be described as indicators of unsustainable boiler operations and causative factors for severe boiler accidents. Among these identified risk factors, some exist due to negligence, while others are a result of management ignorance. Consequently, standard remediation suggestions were provided to the factories after the completion of the inspections.

Moreover, the results of visual inspections help prioritize the most vulnerable factories with primary risks, facilitating the initiation of full-fledged boiler inspections. Full-fledged inspections include internal examination, hydrostatic pressure tests, and functionality assessments. Therefore, analysing visual inspection data should be considered a valuable preliminary step with significant theoretical and practical implications.

For suggesting standardized remediation actions for the existing risk factors, RSC is following several recognized national and international codes such as Bangladesh Boiler Regulations (BBR), Bangladesh National Building Code (BNBC), Indian Boiler Regulations (IBR), National Fire Protection Association (NFPA), American Society of Mechanical Engineers (ASME), British Standards (BS), European Standards (EN), National Board Inspection Code (NBIC), and so on. Table 11 presents the 32 most frequently observed risk factors, clustered into 11 categories, along with remediation suggestions for the factories.

Table 11: Risk categories, risk factors, and remediation suggestions

Risk categories	Risk factors	Remediation suggestions
Boiler Room	The boiler room door swing is not outward directed.	The boiler room door swing shall be directed outside for safe evacuation.
	Combustible materials are stored inside the boiler room.	The boiler and its surroundings shall be free from combustible material storage for ensuring fire safety and visual obstruction shall be removed for proper monitoring.
	Water is dripping/ leaking inside the boiler room.	The boiler room shall be free from slipping hazards.
	The boiler room is not properly illuminated.	Illumination inside the boiler room shall be not less than 150 lux on the floor level for proper monitoring.
	The boiler room does not have adequate explosion release arrangements.	The boiler room shall be provided with a weaker construction in the suitable wall. This area should be at least 10% of the floor area of the boiler room which will release the extra energy from an explosion and save the main structure of the building.
	The boiler room does not have adequate ventilation systems.	An adequate ventilation system shall be ensured as per BNBC for combustion air, habitability, housekeeping, personal safety, and general safety considerations.
	The equipment has insufficient maintenance and inspection clearance.	The front or rear of any boiler shall not be located nearer than 36 inches (915 mm) from any wall or structure. There shall be at least 36 inches (915 mm) of clearance on each side of the boiler and other equipment to enable access for activities.
Documentation	The boiler is found operational without government authorization.	The factory shall have a boiler registration certificate and shall not operate the boiler until the registration certificate is available on-site.
	The boiler registration renewal was expired/ not available.	The factory shall apply to the appropriate authority for a registration renewal certificate and ensure an updated renewal certificate is available on-site.
	The boiler operator has no license.	Any boiler shall be operated by a licensed boiler operator as per Bangladesh Boiler Act and Boiler Attendance Rules.
	Technical documents are not available regarding design and operation parameters.	All required technical documents (see Table 3) shall be available to verify the present condition of the boiler.

Risk categories	Risk factors	Remediation suggestions
Electrical Wiring System	The unterminated live wires are inside the electrical panel.	All the unterminated live power cables must be removed as soon as possible.
	No emergency stop-push switch is available at the entrance outside of the room.	An emergency stop-push switch must be installed outside of the boiler room near the entrance door.
Identification	The boiler manufacturer's nameplate is not available.	The boiler manufacturer's nameplate shall be available on the boiler with proper technical information.
	Adequate technical information is not available for pumps and safety valves	Nameplates shall permanently be fixed on the equipment and readable. The manufacturer's technical documents regarding the equipment shall be provided.
	Inconsistency was observed between the nameplate data and the CIoB-certificate	Information provided in the nameplate and the CIoB-provided certificate shall be consistent. Any alteration shall be approved by the CIoB and a copy to be preserved on-site.
	Registration number plate is not available on the boiler.	The boiler registration number plate shall be made available on the boiler as per the BBR.
Monitoring System	The installed pressure gauge is inadequate in dial size and pressure rating.	An appropriate pressure gauge according to Bangladesh boiler regulation (BBR)/ manufacturing standards shall be provided.
	Inconsistent values are found between pressure gauges.	Appropriate pressure gauges shall be provided with consistent functionality.
	Low-Low Water Level (critically low) was not marked on the level gauges.	The Low-Low Water Level (LLWL) must be marked on the water level gauges.
Burner	Visual flame monitoring glass is broken/ accessible.	The visual flame monitoring glass shall be appropriate and easily accessible for regular monitoring.
Feed Water	Untreated groundwater is used as feed water.	Boiler feed water shall be treated to meet the parameter as per BS EN 12953-10 and recorded regularly.
Fuel Line	The fuel line connection is not terminated properly.	Any fuel line openings in the boiler room shall be diverted outside of the boiler room or sealed off with a bond plug/ blind flange to prevent fuel leakage.
	Fuel line is not constructed with appropriate materials and is not supported and protected against corrosion.	The fuel line shall be constructed with appropriate materials as specified by the manufacturer. Support and protection against corrosion shall be as per the requirements of the gas supply company and NFPA 54.
Safety Valve	Safety valve discharge point is not at outside of room.	The discharge point should be outside of the boiler room. Discharge shall be free from the danger of scalding.
	No drainage arrangement for safety valves was found.	Drainage arrangement must be installed for all safety valves as per manufacturer guidelines or the lowest point of the outlet line.
	Installed safety valves are inadequate according to the manufacturing standard.	Proper sized/ adequate number of safety valves on the boiler shall be ensured following the relevant standard.
	Control valve is observed between boiler and safety valve.	The safety valves shall be mounted directly on the boiler shell without any control valve in between them.
	The safety valve discharge pipe diameter is reduced from the inlet pipe diameter.	The diameter of the discharge pipe of the safety valve shall not be reduced from the diameter of the inlet pipe.
Hot Surface	Boiler body and steam pipes were found with improper insulation.	Proper insulation shall be provided to all equipment in the boiler room that is causing heat exposure of more than 60 degrees Celsius.
	The steam line connection is not terminated properly.	Any unprotected steam line shall be terminated in an appropriate manner that does not create any possibility of burn hazard.

Risk categories	Risk factors	Remediation suggestions
Platform	The boiler handrail, platform, and ladder are not provided/ are inadequately supported.	A Suitable and properly supported boiler handrail and platform shall be provided with proper ladder access.

Figures 8 to 12 present some pictorial evidence of the risk factors of boiler operations in the RMG industry.

7. IMPLICATIONS OF THE STUDY

Industrial managers often need to work under pressure to meet production demand, minimizing the cost, and maximizing profit (Siraj *et al*., 2022). This factor strongly influences the decision-making process, especially in an emerging industry of a developing country. Therefore, the outcomes of this study provide significant assistance in managerial decision-making within the RMG industry's boiler operations. It presents a comprehensive overview of boiler operations, enabling factories to assess their practices and position accordingly (Islam *et al.*, 2022).

Figure 8: Safety valve discharge point inside the room

Figure 9: Different steam pressure at two gauges

Figure 10: No railing for the service platform of boilers

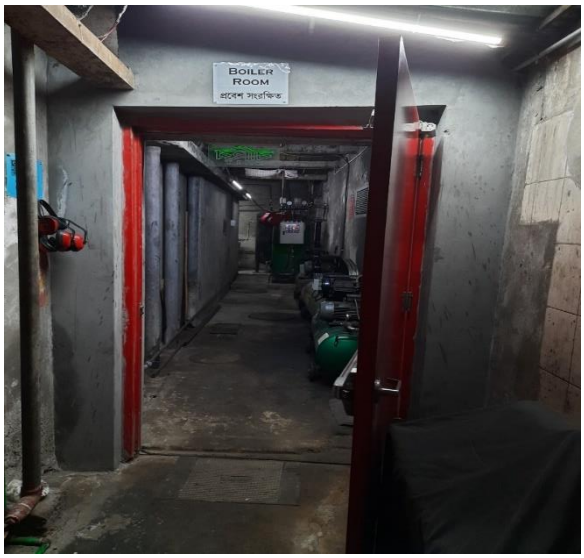

Figure 11: Inadequate clearance, obstructed ventilation

Figure 12: Uninsulated hot surface in the boiler room

The study introduces a method for visual inspection of industrial steam boilers, empowering managers to conduct inspections independently, fostering a sustainable workplace. Additionally, it proposes a categorization framework for steam boilers, aiding in selecting the appropriate type for a factory's specific needs. The research also identifies common risk factors in steam boiler operations, offering targeted remediation strategies for each. It also facilitates the development of a stratified action plan to mitigate these risks effectively, allowing for budget-friendly implementation without requiring substantial upfront investment.

This study holds substantial policy implications for Bangladesh, an emerging economic country, by providing critical insights and recommendations for policymakers. It outlines detailed inspection procedures from a non-government organization that could enhance government boiler inspections. The study also maps the density of major RMG industrial hubs, indicating steam boiler locations for better administrative zoning by inspection authorities. Additionally, it categorizes factories based on their boiler usage, highlighting different operational needs. A significant focus is given to boilers outside the registration scope, suggesting the need for specific policies. The categorization of boilers by manufacturing year and country of origin informs the development of varied operational parameters and import strategies, respectively. The study also underscores the widespread neglect of water softener use, despite existing regulations, pointing out the need for increased awareness among industry owners about sustainable boiler operations. This comprehensive approach aids policymakers in creating more effective and targeted guidelines for the industry.

Boiler operations, integral to safety and productivity, are closely tied to the three pillars of sustainability: social, economic, and environmental (Bari *et al*., 2022; Rahman *et al*., 2022). These operations require vigilant monitoring and management to prevent risks like explosions, contributing to social sustainability (Payel *et al.*, 2023). On an economic front, factors such as uninsulated surfaces and poor ventilation lead to inefficient boiler performance, affecting the overall manufacturing process's productivity (Bari *et al*., 2022). Environmentally, the reliance on fossil fuels in boiler operations, along with high water consumption, presents significant challenges (Fialko *et al*., 2019; Roushan, 2021). This study emphasizes the need for renewable energy adoption and other sustainable practices to overcome these environmental barriers (Saha *et al*., 2021). By offering detailed insights into these operational aspects, the study supports the development of action plans aimed at enhancing safety, efficiency, and sustainability in boiler operations.

8. CONCLUSIONS

The most remarkable aspect of this study is to statistically present the gathered data on 2204 steam boilers used in 1386 RMG factories in Bangladesh. Most of the previous studies on boiler operations in the country were conducted with a theoretical approach due to the lack of empirical data. This study is one of the first attempts in literature to present empirical data on boiler operations in the RMG industry.

External visual inspections of the RMG factories have been conducted by the RSC within the timeline from March 2021 to March 2023. The study categorized the boilers based on different parameters and characteristics. The most frequently observed risk factors in boiler operations and their remediations were also discussed in this study to determine implications for managers and policymakers to achieve sustainability in the workplace in the social, economic, and environmental context.

This study reveals that several unsafe and unsustainable practices currently exist, including inadequate ventilation, use of unsoftened water, poor operational and maintenance practices, reliance on fossil fuels, use of unregistered boilers, and dependency on imports, among others. There is significant potential for improvement in these areas through enhanced managerial excellence and policy implementation. The main goal of this study was to identify these opportunities for development by analyzing the existing scenario. This goal was successfully achieved, making the study a robust contribution to the literature on boiler operational safety and sustainability in Bangladesh.

The study faced some limitations as well. Inspections of boilers are a continuous process by the RSC. Therefore, this study has presented a partial portion of the data from an ongoing project, not the total data from the RMG industry. Moreover, there are a lot of RMG factories that are not in the inspection scope by the RSC. Hence, the RSC can't collect information on boiler operations from those factories. Previous studies depicted that the Accord-inspected RMG factories (continuing as the RSC-inspected factories) are more accustomed to standard practices than the non-inspected factories. Therefore, the boiler operations scenario of those non-inspected factories may be different from this study. In addition to this, external visual inspections cannot ascertain the original physical and operational condition of a boiler. To have a real observation of a boiler, an internal test, a hydrostatic pressure test, and a functionality test is required.

There are several scopes for future research on boiler operations in the RMG industry. This study only utilizes basic descriptive statistical presentation to interpret the gathered data from inspections. Future studies can utilize other statistical tools such as hypothesis analysis and regression analysis to interpret the gathered data from inspections. The enlisted risk factors have not been prioritized in this study. Upcoming studies can utilize any of the multi-criteria decision-making (MCDM) techniques such as AHP, TOPSIS, WASPAS, BWM, and so on to present a ranking of the risk factors based on their severity. Determining barriers to sustainable boiler operations in the RMG industry can also be a prospective study scope. The impact of different unsustainable practices on achieving sustainability can be studied in the future as well.

STATEMENTS AND DECLARATIONS

All the authors of this article were affiliated with the Boiler Safety Department of the RMG Sustainability Council during the preparation of the manuscript. The authors declare that they had no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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