EFFECTIVE CONTROL OF HAZARDS RELATED TO STEAM BOILERS USED IN MANUFACTURING INDUSTRIES IN SRI LANKA

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Occupational Safety and Health Management

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ABSTRACT

Effective control of hazards related to steam boilers used in manufacturing industries in Sri Lanka

Steam Boiler (SB) is the major equipment use in a steam system. It is a pressurized vessel in which heating of water take places and generates steam. It is operated under high heat and high pressure. Therefore, it is considered as dangerous equipment. Many incidents have been reported around the world. This study is focused to control Steam Boiler related hazards found in manufacturing industries in Sri Lanka, by revealing measures to enhance Steam Boiler manufacturing and operation.

A literature survey, a detailed questionnaire survey, and expert interviews were used to collect data. The pilot survey was conducted to make necessary adjustments and validate the questionnaires. Hundred and twenty manufacturing industries were selected as sample. This study sample was selected among the manufacturing industries registered in the Industrial Safety Division of Department of Labour. This was included sixty factories with Steam Boiler related incidents. Steam Boiler related incidents were not reported in other sixty factories. Questionnaire was given to all selected factories and results were analysed using Graphical and Relative Important Index method (RII). Graphical method was used to evaluate the available work practises and RII method was used to identify critical causes of those incidents. Expert interviews were conducted to find expert opinions regarding Steam Boiler operation procedure and manufacturing procedure.

Steam Boiler related hazards are classified as Accidental, Physical, Biological, Chemical, Ergonomic and Psychosocial factors. Only accident type hazards, such as structural explosions, steam leakages fuel leakages were reported in Sri Lanka. The highest number of hazardous incidents was reported in rice mills. Both unsafe actions and unsafe conditions had caused to those incidents. Hazards incidents were not reported in factories with good work practises. Finally, expert suggestions and study results were used to propose strategies to enhance standard of Steam Boiler operation procedure and manufacturing procedure.

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LIST OF ABBREVIATION

CO2 – Carbon Dioxide

CO – Carbon Monoxide

DOL – Department of Labour

HSE – Health and Safety Executive

IIOSH – Israel Institute for Occupational Safety and Hygiene

ILO – International Labour Organization

ISD – Industrial Safety Division

ISO - International Organization for standardization

NIHL – Noise Induce Hearing Loss

OSH – Occupational Safety and Health

OHSAS – Occupational Health and Safety Assessment Series

PPE – Personal Protective Equipment

SB – Steam Boiler

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Chapter 01

INTRODUCTION

1.1 Background

According to Einstein, Worrel and Khrushch (2001) steam systems have major role in industrial processes. Many industries such as Chemical manufacturing plants; electrical power plants; food industries; rice mills; hospitals; plastics industries; steam laundries; hotels; etc. widely need steam for their processes. Steam boiler is the major equipment used in a steam system. One or ranges of Industrial Steam boilers are used to generate steam.

A Steam boiler is a pressurized vessel in which heating of water takes place and generates either steam or hot water. According to the legislation of Sri Lanka, Steam Boiler is described as "any closed vessel in which for any purpose steam is generated under pressure greater than atmospheric pressure" (Factories (Amendment) Law, 1976, p.10).

Industrial steam boilers are available in different types and sizes. Among them, Fire tube boilers, Water tube boilers and packaged type boilers are commonly used in manufacturing industries.

Steam boiler (SB) is operated under high heat and high pressure. Therefore, wide range of safety and monitoring equipments such as alarms, water-level controls, burner controls and pressure-relief valves are fitted to a SB. These equipments had designed to prevent dangerous situations and protect the SB. When it is operating outside the set parameters, these safety and monitoring devices provide warning signals or lead to shut down it (Health and Safety Executive, 2011). In case of malfunction or if these equipments are not available, a dangerous situation can arise without prior notification.

When water at atmospheric pressure, boils till it change to steam, its volume increases and able to produce a huge force. This force has explosive power ("Thermal Energy Equipment", 2006). Steam Boiler related incidents such as Boiler explosions, fire, steam leakages were created as a result of this explosive power. As Table 1.1 no of steam boiler related incidents were reported in Sri Lanka. Deaths, injuries and property damages were reported as a result of those incidents.

Table1.1 Reported Steam Boiler Related Incidents in (2010-2015) in Sri Lanka

District	No of Incidents	District	No of Incidents
Colombo	03	Anuradhapura	05
Gampaha	09	Polonnaruwa	05
Kalutara	03	Ampara	01
Galle	03	Trincomalee	01
Hambantota	02	Batticaloa	01
Kandy	01	Badulla	01
Nuwara Eliya	01	Monaragala	01
Matale	01	Ratnapura	01
Kurunegala	12	Kegalle	03

Source : Statistics of Industrial Safety Division ,Department of Labour, Sri Lanka

As mentioned by the International Labour Organization (ILO), SB operator is a worker who operates steam boilers to provide steam. His job has identified as dangerous. He is working close to high heated pressurized vessel. So, he has direct impact of hazards generated in this work environment.

According to the Factories Ordinances (1942) of Sri Lanka, every SB should be properly constructed with good material and need regular maintenance. Further it should be equipped with all safety devices and need periodic inspection through qualified authorized inspector. Also, the operator should be a license holder to operate a SB. Although this type of legal monitory is available, SB related accidents have reported in Sri Lanka.

According to the occupational safety and health agency for United Kingdom “Health and Safety Executive (HSE)”, SB accidents had occurred as a result of unsafe conditions and unsafe behavior. Inadequate design of SB wrongly sited or wrongly installed SB as well as incorrect operation and maintenance of SB were identified as causes of SB accidents (HSE, 2011).

1.2 Research Problem

Although SB incidents has been identified as a problem in Sri Lanka, many research works have done only on the purpose of improve SB efficiency and minimize the emission of pollute substances. Still its hazardous nature has not been discussed properly.

Sometimes no of SB related incidents had reported in Sri Lanka (Table 1.1). Worker injuries, thermal burns, permanent partial disabilities, fatality or property damages had reported with those incidents. Such an explosion may affect people living in two or three kilometers away from the SB plant. Further it may damage structures and other properties position in the subjected area. Therefore, it is important to find out “what are the actual causes behind these hazardous incidents”.

SB operators have to work in a noisy, hot and humid environment. They come into contact with various substances such as fuel, water additives, etc used in these steam boilers. There is a possibility to emit Carbon monoxide, Sulfur Dioxide or other poisons during fuel burning of SB. Asbestos are used as insulated material of the SB and steam pipe lines. During a major maintenance work, maintenance workers expose to asbestos dust and fiber. Under these circumstances ILO has mentioned the possibility of exposed to different hazards in normal SB attending work. Hence it is necessary to identify “types of hazards generate during SB operation”.

Though safe practices, monitoring regulations and rules are available, as details in the Table 1.1, still SB related incidents have reported in manufacturing industries in Sri Lanka. Hence it needs to identify gap between current work practices and recommended safe practices.

After identify weakness of available practices, it is important to find out required improvements of current methods which help to ensure safety of SB workers.

1.3 Aim

This research is focused to minimize SB accidents and minimize SB related other incidents by revealing measures to enhance SB manufacturing and SB operation procedures.

1.4 Objectives

1. Identify Steam boiler related hazards found in manufacturing Industries.
2. Analysis causes of Steam boiler related hazards.
3. Identify level of available work practices
4. Propose strategies to enhance Steam boiler manufacturing procedure
5. Propose strategies to enhance Steam boiler operation procedure

1.5 Research Methodology

A literature survey, a detailed questionnaire survey, and expert interview were used to collect primary and secondary data.

- **Literature Survey**

A comprehensive literature survey was conducted by referring books, journals, research articles, and other publications. Previous Research articles and internationally recognized occupational safety and health publications were referred to find details about SB, boiler attending staff, causes and results of SB failures. Further it was used to identify SB related hazards (objective 01) and available hazard control measures.

- **Data collection**

Both primary and secondary data were used in this research. Secondary data were obtained from the details collected in the Industrial Safety division (ISD) of Department of Labour (DOL).

Primary data were collected through detailed questionnaire survey and expert interview.

- **Pilot Survey**

A pilot survey was conducted to make necessary adjustments and validate the questionnaires. The trial questionnaires were distributed among selected five managers of manufacturing industries. Then required adjustments were made with the help of experts from the Industrial Safety division.

- **Questionnaire survey**

A detail questionnaire survey was conducted to identify boiler related hazards, causes of these hazards and current work practices (Objectives 2 & 3). Questionnaire was prepared with the guidance of literature survey and adjusted according to the pilot survey findings. The questionnaire was distributed among factory manager of randomly selected hundred and twenty manufacturing industries. These were included sixty factories with SB related incidents. Other sixty were selected from "no incident group". Steam Boiler related incidents were not reported in those factories.

- **Expert Interview**

Expert interview was conducted to obtain experts opinions about SB failures, hazards and collect suggestions to improve SB manufacturing and operation procedures.

Five experts in the field of OSH were interviewed to collect details. These experts were selected from Industrial Safety and Occupational Hygiene Divisions of Department of Labour. The interview guide line was prepared based on the findings of literature survey and the questionnaire survey. The interview was focused to collect suggestions to improve SB operation and manufacturing processes. Finally,

those data were used to propose strategies to enhance SB operation procedure and SB manufacturing procedure (objectives 4 & 5).

- **Data Analysis Techniques**

The data and information collected through the research were analysed using qualitative and quantitative data analysis techniques. Statistical analysis was used to analyse the results of the questionnaire survey. Descriptive analysis was used to analysis expert opinions about SB operation procedure and SB manufacturing procedure.

1.6 Scope and limitations

This research was targeted to identify hazards related to steam boilers used in medium scale manufacturing industries in Sri Lanka and find out causes of those hazards and suggest measures to control their impact.

This study is focused and limited only to "steam boilers" used in "manufacturing industries" in "Sri Lanka". That data was only considered depend on the time and resources available. In this study medium scale manufacturing industries registered in Industrial Safety Division (ISD) of Department of Labour were considered as study population. Incident data were only reported incidents to the ISD.

1.7 Chapter Break Down

This dissertation report was structured into five chapters.

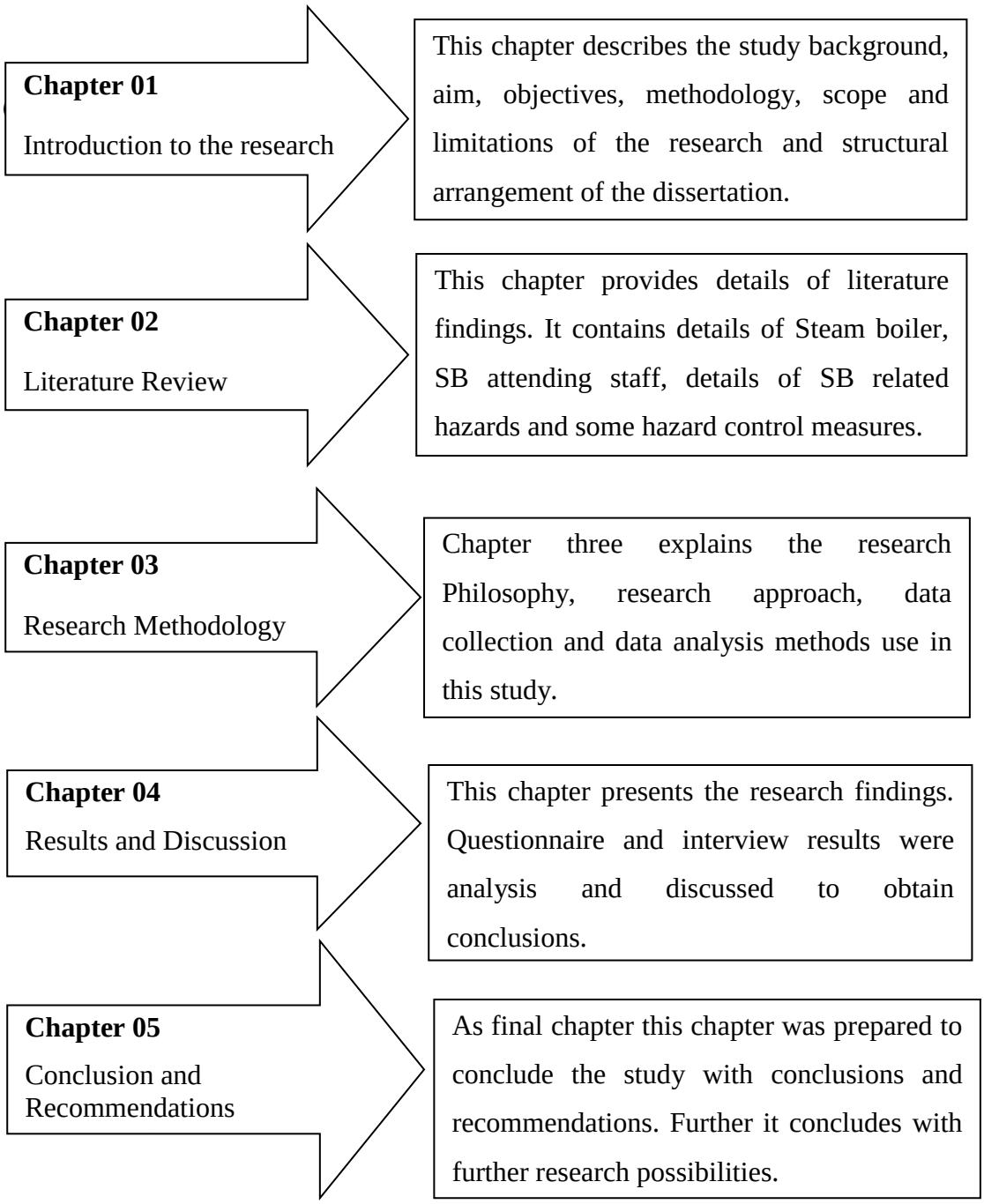


Figure 1.1: Chapter breakdown

Chapter 02

LITERATURE REVIEW

2.1 Introduction

Steam is the gas phase of water. It is used for energy storage in industrial applications. Steam systems have important role in major industrial processes. Industries such as Food processing, Pulp and paper, chemical, primary metal-based industries, petroleum refining industries consume significant amount of fossil fuel for steam production (Einstein, Worrel, & Khrushch, 2001). Steam boiler is used in steam generation process. Therefore, steam boilers are widely used in manufacturing industries. As example, in Sri Lanka a vertical or horizontal SB is used to produce steam in a rice mill. This steam is used for parboiling and drying paddy in the rice mill. Further in the milling process, high pressure steam is supplied to hot soaked paddy to increase kernel moisture from 26% to 36% (Roomi, Namal, & Jayasinghe, 2007).

Steam Boiler is a pressure vessel. When water at atmospheric pressure boils into steam its volume increases about 1,600 times. Then it is able to produce a force that is almost as explosive as gunpowder. Therefore, SB must be treated very carefully ("Thermal Energy Equipment", 2006). In every year, many accidents and dangerous occurrences reported in Sri Lanka as well as around the world. These accidents and incidents have significant effect of the occupational safety and health of SB attending staff.

According to ILO, it is easier to design and implement suitable preventive methods only with the knowledge of what causes injuries and diseases. Many professionals, organizations and researchers had studied about safety matters of SB, had given suggestions to mitigate hazardous nature of it. Their study details can collect as research papers, text books, web publications, etc. This chapter is created to compare, summarize, synthesis and critique their individual work.

The main body of the chapter includes brief details about SB, and attending staff. Further it describes the details about SB failures and associated occupational hazards. Finally compare and summarizes available hazard elimination and mitigation methods suggested by different researchers and professionals.

2.2 Overview of Steam Boiler

"A boiler is an enclosed vessel that provides a means for combustion heat to be transferred to water until it becomes heated water or steam. The hot water or steam under pressure is then use for transferring the heat to a process" ("Thermal energy Equipments, 2006). According to the Factories Ordinance no 45 of 1942 of Sri Lanka, SB is considered as a closed vessel which used to generate steam for any purpose under pressure greater than atmospheric pressure.

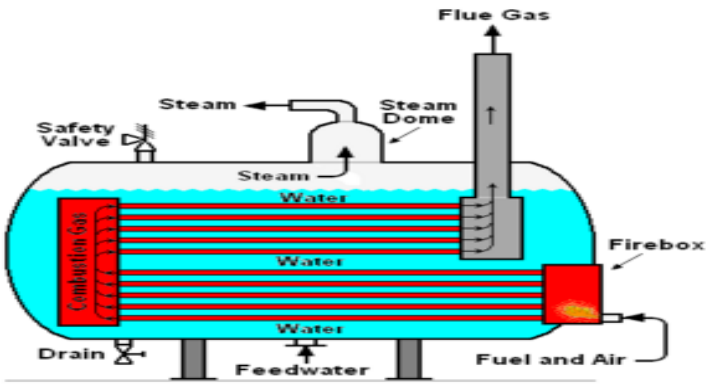


Figure 2.1 A view of steam boiler

Steam boiler consists of shell (main body of the SB), closure heads, openings for inspection and instrumentations, attachments and a combination of other supports (Chattopadhyay, 2004). Wide range of safety and monitoring equipments such as alarms, pressure relief valves, water-level indicators, and burner controllers are attached to a SB. These valves and gauges ensure the safe operation of the SB (HSE, 2011). In Sri Lanka every SB which is used in a factory, should be attached with a suitable safety valve to prevent the SB being worked at a pressure greater than maximum permissible working pressure. Suitable pressure gauges should be connected to the steam space and steam pipe line of the SB to identify the steam pressure. A water level indicator (water gauge) should be connected to show the

water level inside the SB. Further it should have facilities for attach a test pressure gauge. If SB is not fired externally, it is necessary to provide a suitable fusible plug or an efficient low water alarm device (Factories Ordinance, 1942, p.506-507).

The feed water system provides water to the SB. The steam system control and distribute the steam produced in the SB. Steam is directed through a piping system to the end user. Steam pressure is regulated throughout the system, by using different type of valves and pressure is monitored by using pressure gauges. The fuel system includes the necessary equipments to supply fuel to generate heat ("Thermal energy Equipments", 2006).

2.2.1 Types of Steam Boilers

There are various types of steam boilers available. Fire tube boilers, Water tube boilers, and packaged boilers are common types use in manufacturing industries.

In a fire tube SB, boiler feed water in the shell side is converted into steam. This is done by using hot gases which passes through the tubes. These are generally used for small steam capacities and low to medium steam pressures. This type of steam boilers can be used with oil, gas or solid fuels. In a water tube SB feed water flows through the tubes. This circulated water is heated by the combustion gases. So the water converted into steam at the vapour space in the drum. These are used, when steam demand as well as steam pressure requirements are high. The packaged type SB comes as a complete package. It requires only the steam and water pipe-work, fuel supply and electrical connections to become operational. Normally these steam boilers are shell type with fire tubes design so as to achieve high heat transfer rates ("Thermal Energy Equipment", 2006).

2.3 Steam Boiler Attending Staff

According to the ILO (2012) SB operator is a worker who operates steam boiler to generate steam that supplies heat or power for buildings or industrial processes. Steam Boiler operator is the person who is always working with the SB. Boiler maker; boiler-house inspector; boiler-house mechanic; boiler-operator helper; boiler-

shop supervisor; boiler-tube blower; Control-room operator; Steam-generator operator; are other related and specific occupations of the SB.

2:4 Hazard

According to the Occupational Health and Safety Management System requirements published in ISO 45001:2018 by International Organization for standardization (ISO), Hazard can define as "Source, or situation with a potential to cause injury or ill health" (ISO 45001:2018).

2.5 Hazards Related To Steam Boiler

Steam boiler attending staff has direct influence in case of any dangerous situation. The employees who work in recovery SB areas in pulp manufacturing mills have possibility of expose to liquid splashes, at temperatures up to 800-900°C (Maki, Koskinen, & Makinen, 2006). Those workers had faced serious skin burns when they were doing cleaning and maintenance work of a SB (Maki et al., 2006). According to the publications of ILO and IIOS (2000) boiler operator face many dangers during his job. ILO has listed these dangers under five hazard types.

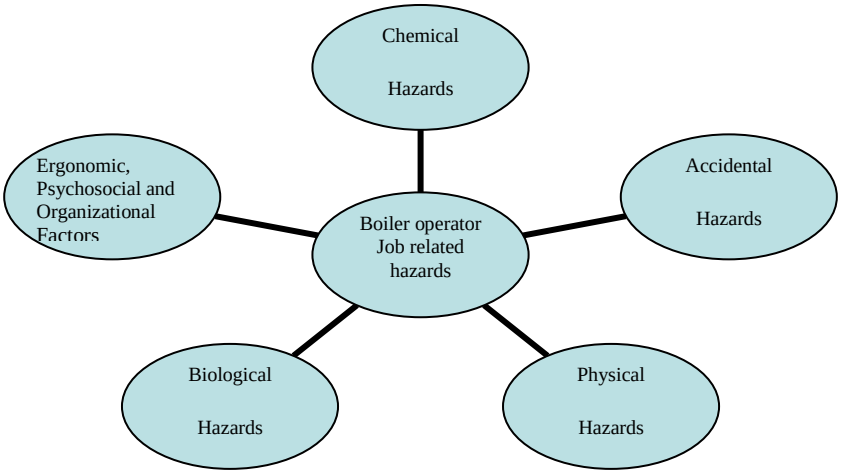


Figure 2.2: Steam boiler operator job related hazards

Source: International hazard data sheet on occupation (2000)

2.5.1 Physical Hazards

Noise, vibration and heat stress are key physical hazards (Arandara, C. Jayasinghe, & Jayasinghe, 2011). According to publications of ILO (2012) SB operators have to work in a noisy, hot and humid environment.

Workers ability to do his or her job is affected by the hot or cold work environment. Especially it is necessary to maintain comfortable temperatures inside the workplace for productive work. Any worker can face following safety and health problems as a result of too much heat in his or her work surrounding (ILO, 2014).

Heat stress has direct impact on Occupational health of a worker. It is identified as a "hyperthermia" situation. It means "higher body temperature" as a result of thermo regulation failure. It occurs when the body absorbs heat more than it can bear (Arandara, C. Jayasinghe, & Jayasinghe, 2011).

Table 2.1: Safety and Health problems if high heat reported in the work environment

Safety	Health
• Fatigue and dizziness • Sweating palms (become slippery) • Fogging of safety glasses • Possible burns • Lower performance/alertness	• Heat stress/strain (distress) • Heat cramps • Heat exhaustion/heat stroke • Heat rash (prickly heat) •Fainting (syncope)

Noise is defined as unwanted or unpleasant sound. It can cause many effects including Noise Induce Hearing Loss (NIHL). This creates a social problem. Workers suffer from NIHL difficult to hear work instructions. Work instructions and other information should be repeated for them. So, they are left out from conversations. Finally, these workers tend to be isolated and alone. Noise can cause stress and interfere with concentration. Any worker who losses his concentration, can easily meet an accident. Long term stress can lead to number of health problems. As example, workers expose to high noise levels face many difficulties. They suffer from noise induce headaches. They have sleeping difficulties at night. Poor work

attendance and low work performance are common problems among those workers (ILO, 2014). According to the ILO and Israel Institute for Occupational Safety and Hygiene (IIOSH) (2000) SB operator has a risk of having following health effects.

Table 2.2: Boiler operator job related physical hazards

Type of Hazard	Hazard	Effect
Physical Hazard	1. Excessive Continuous noise Levels – as high As 94 dBA	Hearing Impairment
	2. Prolonged work at high temperatures and relative humidity	Heat Stress
	3. Potential Exposure to radon (Sometimes)	Illnesses

2.5.2 Biological Hazards

According to the ILO (2012) the high humidity and temperature environment can create biological hazards. Elevated temperature and humidity help to grow bacteria and development of fungi inside the SB room. These bacteria and fungi are considered as Bioaerosols and often induce disorders in reciprocating system or skin (Rim & Lim, 2014). Presence of rodents and some insects inside the SB room may result in bites and infectious diseases.

Still most industries use wood fired steam boilers. As example most of the desiccated coconut mills in North Western province Sri Lanka use firewood steam boilers to generate steam for pasteurization/sterilization in desiccated coconut production process (Kumar, Senanayake, Visvanathan, & Basu, 2003). Wood fuels are subjected to biological and chemical reactions during storage and decomposition. Bacteria and fungi are main cause for this reaction. Health hazard can arise from airborne particles and microspores (Laitinen, Fagernas, Korpijarvi, Ojanen, & Jokiniemi , 2016).

2.5.3 Chemical Hazard

In normal SB operation, SB operators come into contact various substances such as fuel, water additives, etc. According to the publications of ILO (2000) these substances and content of the flue gas may have several health effects as below.

Table 2.3: Boiler operator job related chemical hazards

Type of Hazard	Hazard	Effect
Chemical Hazard	1. Burning of high – sulfur fuels	Irritation of the upper respiratory tract and coughing as a result of inhalation of Sulfur Dioxide.
	2. Exposure to vanadium – containing dust during maintenance and repair work	Pneumoconiosis
	3. Exposure to respirable fly ash	Pneumoconiosis
	4. Exposure to fuels , corrosion inhibitors and other water additives	Dermatoses
	5. Asbestos as an Insulation	Cancer
	6. Exposure to hydrazine and its derivative, used as additives to SB water	Irritation of eyes, skin and respiratory tract

Both Liquid fuels and Solid fuels used in the boiler burning system. Paddy husk and wood are common solid fuels. During both wood and fossil fuel burning more than ten percent of Carbon Dioxide (Co_2) emission has reported. In case of insufficient air supply or surplus fuel supply incomplete combustion has reported ("Thermal energy equipment", 2006). Carbon Monoxide (Co) is a product of incomplete combustion. "Carbon monoxide binds to hemoglobin, modifying its conformation and reduces its capacity to transfer oxygen. This can affect the function of different organs (and

especially high oxygen consuming organs such as the brain and the heart), resulting impaired concentration, slow reflex, and confusion" (Badman & Jaffe, 1996).

As some studies wood smoke contains Co and Nitrogen dioxide and fine particles with several other pollutants. The direct exposure may have impacts on the respiratory immune system. High doses can produce long-term or permanent lesions in lung tissues (Naeher et al., 2007).

Asbestos has been used as insulated material of SB. This insulation material is loosened during a major maintenance or broken up of the SB. During this process some of the padded asbestos, torn and spread around the workshop. The remaining asbestos is brushed away with brushes of steel after SB being dismantle. As a result, the workshop air is mixed with dusty asbestos particles. The workers exposure and inhale this carcinogen dust have become cancer patients.

2.5.4 Ergonomic, Psychosocial and organizational factors

Noisy, hot and humid work environment may cause tiredness and general ill-feeling. It creates both physical and mental unsatisfaction.

Table 2.4: Boiler operator job related Ergonomic and Psychosocial hazards

Type of Hazard	Hazard	Effect
Ergonomic Psychosocial and Organizational Factors	1. Physical work in a noisy, warm and humid environment	General tiredness
	2. Continuous repetitive moments or over strenuous efforts	Cumulative trauma disorders
	3. Over exertion and wrong postures, during lifting and moving of sacks and heavy loads	Back pains and other musculoskeletal problems
	4. Dissatisfaction at work	Psychological stress.

2.5.5 Accidental Hazards

Both ILO (2000) and Ladokun, Nabhani, and Zarei (2010) had mentioned about possibility of SB accidents. According to their findings all pressure vessels including SB should be properly designed, constructed, installed, operated, repaired, modified and should have proper pressure releasing system. Otherwise explosions or fires are possible to occur after any major SB failure. Property damages, thermal burns, Loss of lives, permanent injuries or disabilities on affected people are end results of such type of accident.

Table 2.5: Boiler operator job related accidental hazards

Type	Hazard	Effect
Accidental Hazard	1. Fuel leaks	Fires and explosions
	2. Explosions of gas air mixtures within the Steam boiler	Steam Boiler explosion
	3. Overheating and over pressure	Bursting of Steam Boiler
	4. Failure of Structural Components due to metal fatigue (overheating and over pressure)	1. Fires 2. Injury by the explosion
	5. Hot surfaces, hot water and steam	Burns
	6. Damage circuits	Electrocution or electric shock
	7. Floors made slippery by water, fuel, oil	Slips and falls
	8. Floors made slippery by water, fuel, oil	Slips and falls
	9. Splashes into the eyes of chemicals (hydrazine and its derivatives)	Permanent corneal lesions
	10. Splashes of hydrazine and Its derivatives	Human skin may cause penetrating burns and severe dermatitis
	11. Work at height	Falls from ladders stairs and elevated platforms

Table 2.6: Steam boiler related accidents

	Accident	Result	Study Findings (Cause of Accident)
1	Explosion of a Steam boiler	Surrounding Property damage, fatal accidents and human injuries	1. Operational Errors made by unskilled workers 2. Locally design and fabricated SB with faults 3. Safety valve not working 4. Shortage of boiler water
2	Fuel oil pipe leakage	SB fire and burnt injury of a SB Operator	Poor maintenance of steam boiler and auxiliary equipments.
3	Boiler fuel splashing on the Hot surface	Fire and burnt injury of a boiler Operator	1. Poor maintenance of SB and auxiliary equipments. 2. Malfunctioning of fuel system
4	Steam and hot water rushed out from a Crack opened cover of steam receiver	Serious scald of the boiler operator and his death due to those injuries.	1. Untrained worker. 2. Lack of supervision 3. Poor maintenance
5	Burst opening of a steam manifold end plate	Fatal accident	1. Defective steam Manifold 2. Steam Boiler had not inspected by authorized inspector.
6	Serious tube failure and leakages	Unsafe to operation	1. Poor maintenance 2. Unauthorized boiler tube repair.
7	Explosion of the steam receiver	Serious damage to the premises and a Fatality	1. Unskilled operator 2. Work without safe operation procedures and safety equipments. 3 Unauthorized alternations

In every year SB related accidents reported around the world. These accidents were investigated and analyzed to identify the actual reasons behind them. Occupational Health and Safety branch of Department of Labour Hong Kong had done detail study of SB and other pressure vessel related incidents reported in Hong Kong. Steam

Boiler accidents reported in Sri Lanka were investigated by Engineers of ISD of DOL. In those cases, people died or injured and property damages had reported. Some of those study details were summarized in above Table 2.6.

These types of studies are important to make recommendations for accident prevention and stop recurrence.

2.6 Steam Boiler Failures

Ladokun, Nabhaniand Zarei (2010) and Abouelrish and Soetjahjo (2013) had identified many causes for SB failures. Those failure details were summarized as Table 2.7.

Table 2.7: Steam Boiler Failures

	Failure originate Area	Cause of failure
1	Steam Boiler Manufacturing	1. Faulty design 2. Improper selection of materials 3. Defects of material 4. Welding and other Fabrication Errors 5. Improper installation
2	Steam Boiler operation	1. Mal functioning of safety valve 2. Low water condition 3. Operate above maximum allowable working pressure 4. Overheating and over pressure
3	Behavior of Steam Boiler staff	1. Operator errors 2. Unsafe work practices 3. Work without necessary skill
4	Steam Boiler Inspection	1. Failure to inspect during regular periods. 2. Under Investigation 3. Recommended repairs not done after inspection

2.6.1 Behavior of boiler staff

A SB failure can occur as a result of an unsafe action of SB attending staff member. Some people have their own beliefs and habits which they are not willing to change. Staruck (1996) had stated **"**Often, before they can learn something new, people have to unlearn what they think they already know. That is, they may have to discover that they should no longer rely on their current beliefs and methods." Same principle is applied in SB operation and related activities. Even though proper and most safe procedures are available, workers are trying to apply their own methods. This behavior of boiler staff increases the hazardous nature of a SB.

- Forgetting to open a valve;
- Opening the wrong valve;
- Opening a vessel before releasing the pressure;
- Pressing the wrong button, are few mistakes made by an operator, which caused to a SB accident. Those were identified as attitudes towards errors. In those cases, workers training or ability is not the reason. They know right work and capable of doing it. Further stress and distraction have great impact on these human failures. Organizations with safe work systems use interlocks or checking procedures, fully automatic systems as this type of danger control methods.

2.6.2 Steam Boiler operation

A SB system has three modes of operation: SB startup; SB operation, and SB shutdown. Each mode has set of parameters to ensure the safe operation. Improper SB operations create a path to SB explosions and other accidents. Morrison, Fecke, and Ramirez (2012) had identified low water level and loss of combustion air supply as two major factors which cause the SB operation failures.

Low Water Level; Steam Boilers transfer high heat to pressurized water to generate steam. Water level of a SB is observed through gauge glasses. Water level in gauge glass may not be visible if it is not cleaned properly. Then the SB operator does not know the correct water level. Placing too much attention on auto water level

controller is another problem. Further water level decreases as a result of insufficient water supply from the feed water tank or leakages of the water supply system.

Further, according to N.Tapaswi (personal communication, October 1st, 2015) these types of negligence are end up with water shortness of the SB. In case of water loss or shortness, overheating results in loss of metal properties of SB shell, tubes and other metal parts. This causes development of bulges to furnace or headers and distortion of tubes. At last a SB explosion can occur.

Loss of combustion air; In air burn SB loss of combustion air supply or control may lead to accumulation of unburned fuel in the furnace. Normally an air flow switch is installed in air duct. It provides proof of air supply according to the design conditions. But no guarantee about sufficient air supply during a mechanical failure of that device. Further air flow switch does not provide details of actual air flow rate. If air supply is ineffective it leads to furnace explosions (Morrison, Fecke, & Ramirez, 2012).

Flue gas Explosion; If unburned fuel mix with sufficient air and received heat to increase mixture temperature up to ignition point then this type of explosion can occur. According to N.Tapaswi (personal communication, October 1st ,2015) Fuel valve leakages, loss of ignition, failure of ID fan, secondary combustion of fuel create such type of explosions. The end result is a SB accident.

2.6.3 Steam Boiler construction and installation

Steam boiler construction and installation has significant importance to ensure safety. Ladokun, Nabhani and Zarei (2010) had mentioned the importance of standards and codes laid down by approved regulatory bodies for the design, construction, welding, testing, marking, operation, inspection, and repair of SBs. These standards and codes such as ASME Boilers and Pressure Vessel Codes, API Standards, British Standards, European Codes and Standards, etc vary from country to country. These standards and codes provide basic safeguards and good safety practices (Ladokun, Nabhani, & Zarei, 2010).

As another study (Giacobbe, Platania, Sili, Iacino, & Corso, 2014) Pressure equipments have to work in safe conditions, even if pressure, temperature and environmental conditions change.

According to Giacobbe et al. (2014) steam boilers have more tendencies to corrode under chemical and physical environmental conditions. Cracks are possible to appear on shell body with shell material (steel) deformation. Therefore Eccher (as cited in Giacobbe et al., 2014) had mentioned the requirement of proper material and protection system selection at the time of manufacturing.

According to N.Tapaswi (personal communication, October 1st, 2015) some accidents had happened as a result of the way of SB supporting system installation. Some fuel tanks as well as feed water tanks are installed just above the SB. Overflow or leaks of fuel from fuel tank may fall on SB. It creates fire hazard or SB explosion. In case of water leakage or overflow, pressure parts distort or corrode and they are not working properly.

Further Giacobbe et al. (2015) had stated the test requirement of SB after installation. This testing should be complied with legal requirements. These legal requirements differ from country to country. In Sri Lanka, new SB or used SB cannot use without test certificate obtain from manufacturer of the SB or from the SB inspection company. The certificate should be included specific details such as maximum permissible working pressure and nature of tests carried out (Factories (Amendment) Law, 1976, p.9).

2.6.4 Steam Boiler inspection

In his study Giles (1992) had stated importance of SB inspection. According to him, SB inspections are conducted to ensure the plant efficiency and safety of the plant. Steam Boiler inspector should be ensured that there isn't any danger from explosion either in the furnace or from the water side. In his inspection, inspector checks the furnace for excess oil collection, functions of pressure relief valves, cleanness of vent

pipes, thermostat operation etc. These are very important to ensure safety (Giles, 1992).

In another study Kunreuther, McNulty and Kang (2002) had mentioned the importance of third-party inspection of a SB. According to Kunreuther et al. (2002) theses inspections are conducted to check whether SB is safely and satisfactorily operating. It helps to identify construction faults and maintenance requirements. Kunreuther et al. (2002) had further mentioned the importance of regular inspection rather than made regulations.

2.6.5 Steam Boiler maintenance

Same as SB inspection, SB maintenance and monitoring assists to ensure safe operation of a SB. It may be a contractor work or company itself can do it. It includes regular service of boiler controls, valves and other attachments. It helps to identify SB problems by owner himself (Giles, 1992).

According to Ladokun, Nabhani, and Zarei (2010) SB or pressure vessel can fail as a result of corrosion of vital parts of it. Corrosion may attack the internal or external surfaces or both, of plant. Thereafter Corrosion reduces the strength of SB below that was intended in design. Such failure has significant damagers to the SB and users.
There are two major types of deposits found in SB. One is form as a result of calcium and magnesium hardness salts. The other one is iron, which is the main deposit agent (Turner, 1980). According to the Turner (1980) feed water supply from wells and surface water contain iron. So, this type of water can be corrosive to both steel and cast iron water supply lines. Further corrode walls of feed water line, economizer, and the condensate system generates iron. These particles easily mix with water. Finally, these impurities can deposit inside the SB tubes. It may cause tube failures, corrosion and overheating. Therefore Turner (1980) had mentioned the necessity of feed water treatment and corresponding system maintenance.

2.7 Control Measures to Minimize Hazards

According to the previous details provided in this chapter most of the research works were conducted to identify the causes of SB failures. These failures have direct or indirect effect for a SB hazard. Some of these literatures include the important SB failure control methods.

International Labour organization (2010) has mentioned several safety practices which help to secure from physical, chemical and accidental hazards. It had highly recommended to use correct size and type of Personal Protective Equipments (PPE) such as safety shoes, eye goggles, chemical resistant gloves, protective clothing, during SB construction, operation and maintenance work. These equipments are used to minimize effects from chemicals, noise, and harmful dust and other materials. Replacing hydrazine with less hazards substitute is another solution to prevent both chemical and accidental hazards.

According to the publications of ILO (2010), proper ventilation methods help to minimize effect of acute CO or other combustion product poisoning. Suggestions have given to install effective exhaust ventilation and local exhaust ventilation to prevent air contamination.

Researchers had mentioned that the "Periodic SB Inspection is important to identify functional and structural failures of a SB". Otherwise these failures are end up with serious disasters. ILO (2010) had suggested periodical inspections and adjustments of SB burner to prevent CO generation. Those inspections help to identify SB structural failures such as metal cracking and detect component failures (ILO, 2010). According to Kunreuther, McNulty and Kang (2002) third party inspection is more important than command-and-control procedures. They had mentioned the value of SB inspection by a qualified inspector between specific time periods. It creates mutual relationship between two parties. Especially this helps to share technical knowledge to small industries where the hazard control programme is not effective or insufficient. Further Giles (1992) had discussed the importance of SB inspections

to ensure the plant safety. He had mentioned the check requirement of various SB parts to ensure proper functioning of a SB.

Ladokun, Nabhani and Zarei (2010) had mentioned the importance of recognized standards and codes during design, construction, operation, maintenance, and inspection work of a SB. Few internationally recognized standard codes are available for steam boilers and other pressure vessels. Abouelrish and Soetjahjo (2013) had also mentioned the SB hazards and safety control methods. They had further mentioned the requirement of international standards and safety regulations for hazard control.

According to Ladokun et al. (2010) SB should be operated below maximum working pressure. Proper pressure settings of relief devices are essential to ensure safe operation.

Providing safety training on job related hazards and anticipated conditions is helped to prevent hazards. According to Ladokun et al. (2010) operators should be trained periodically to provide adequate and suitable instructions for safe operation.
As their study SB maintenance is another important area to ensure SB safety. Keeping records of inspection reports and monitoring potential problems are key requirements to prevent dangers. It is essential to conduct alterations or repairs of vessels only by competent and authorized persons. Those repairs must meet the accepted industry quality standards for pressure vessel repair (Ladokun et al., 2010).

2.8. Summary

Steam is widely used in manufacturing industries spread around the world. Steam Boilers are operated to generate steam. Depending on its explosive nature, SB is identified as a high-risk machine. ILO has listed SB operator job related hazards under chemical, physical, accidental, biological, ergonomic and psychosocial types. According to the literature findings, property or life loss or serious health impact can occur as a result of SB hazard. But many people still work with SB.

Several research activities had taken by professionals and interesting parties to identify, minimize and eliminate these hazards. According to their study details, SB design, construction, operation, maintenance and inspection errors, and behavior pattern of SB operator have significant impact on SB hazards.

According to the literature survey, few internationally recognize standards and cords are already available to guide SB design, manufacturing, installing, operation, maintenance and inspection. Researchers had mentioned the importance of use of these standards.

In most countries laws and regulations were introduced to ensure SB safety. This legal compliance is helped to minimize SB hazards. Periodic inspections of SB are also important to identify faults and defects of it. Even though SB operators are well trained and experienced workers, it is necessary to train these workers regularly.

Chapter 03

RESEARCH METHODOLOGY

3.1 Introduction

In previous two chapters research problem was identified and the relevant literature was reviewed to prepare a background to the research work. This chapter gives the description of the methodological frame work adapted in the study. It describes the research design, research philosophy, research approach, data collection techniques, sampling method and data analysis method.

3.2 Research Design

As illustrated in Figure 3.1 in this methodology, research philosophy is positioned at the outer layer of the 'research onion'. It leads for research approach and research approach leads to research techniques.

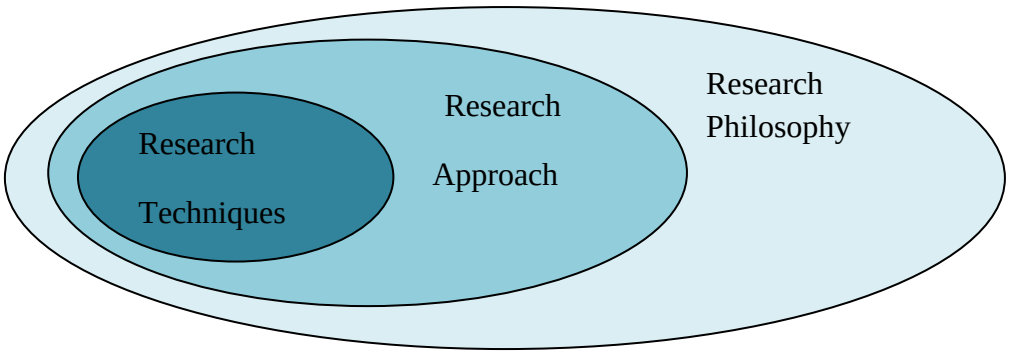


Figure 3.1: Research Design

3.2.1 Research Philosophy

In a research study, researcher collect data and analysis those data to answer the research question. This answer leads to create new knowledge. In every stage of this process researcher makes number of types of assumptions. The term "Research Philosophy" refers to a system of beliefs and assumptions about the development of knowledge (Saunders, Lewis, & Thornhill, 2015). A well organized and consistent set of assumptions constitute a research philosophy which leads to proper research approach, data collection techniques and analysis procedures.

Under “Pragmatism philosophy” researcher can view research problem by multiple methods to find answer. Therefore, this research was based on the “Pragmatism philosophy” concept as research strategy contains both qualitative and quantitative data collection procedures and data analysis techniques.

3.2.2 Research Approach

According to the Tan (2002) research approach is the plan which takes research question to a conclusion. Selection of a research approach is based on the nature of the problem, objectives of the study and personal experience of the researcher (Creswell, 2014).

When research starts with theory, often developed from reading of the academic literature and designs a research strategy to test that theory, it is called deductive approach**.** Conversely, if the research starts by collecting data to explore a phenomenon and generate conceptual framework (build theory), then it is called an inductive approach. In these two cases both qualitative and quantitative strategies are used to reach destination. Sometime these two approaches use together as combine or mixed approach. According to Creswell (2014) this combine approach provides more complete understanding to the research problem.

It is the responsibility of the researcher to find out most suitable strategy according to the expected research outcome (Saunders, Lewis, & Thornhill, 2015).

In this study available facts and details obtain from the literature survey were checked by using field survey method. Later those survey findings and expert interview findings were used to prepare a strategical framework. So, this research study was based on mixed method. Both qualitative and quantitative data collection methods and data analysis methods were used in the study.

3.2.3 Research Techniques

Research techniques include the method of data collection and data analysis. Both primary and secondary data are used in research studies. According to the Tan (2002) interviews, questioner surveys, observations, experiments, etc are used as data collection methods.

In this study questionnaire survey and expert interview were used to collect primary data. The relevant Secondary data was extracted from the records of Industrial Safety Division of Department of Labour Sri Lanka.

Those data were analyzed using statistical and detail analysis methods.

3.3 Research Process

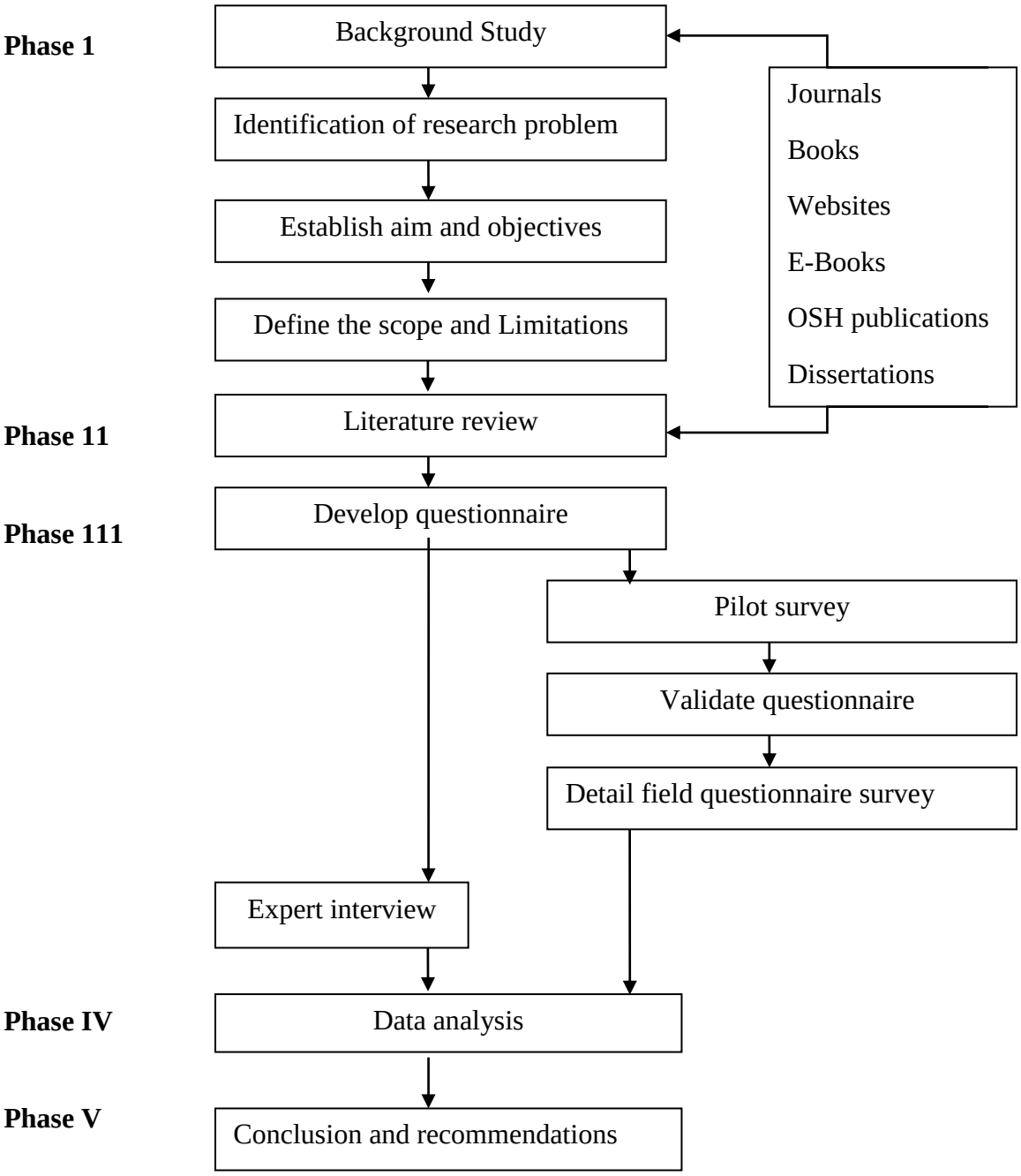


Figure 3.2: Research Process

3.4 Data collection

Both Secondary and Primary data were used in this research process. As mentioned in above, relevant Secondary data was extracted from records of Industrial Safety

Division of Department of Labour Sri Lanka. Primary data were obtained in three phases. They are pilot survey, questionnaire survey and Expert interview.

3.4.1 Pilot Survey

According to the Naoum (2013) pilot survey provides trial run for the Questionnaire. It is important to test wording of questions, identify ambiguous questions, test the technique that use to collect data, etc. Therefore, pilot study helps to conduct main survey without difficulties.

So, in this study, a pilot survey was conducted

(i) to make necessary adjustments of the Questionnaires

(ii) to validate the questionnaires.

(iii) as a trial run

The trial questionnaires were distributed among selected five managers from manufacturing industries. Then required adjustments were made with the help of experts from the Industrial Safety Division.

3.4.2 Questionnaire survey

Detail questionnaire was prepared with the guidance of literature survey and adjusted according to the pilot survey findings.

3.4.3 Questionnaire design

The questionnaire was prepared by using literature findings and adjusted after pilot survey. The structure of the questionnaire contained three sections.

1. Background details of the Steam Boiler, Steam Boiler operation and the Incident.
2. Focus on cause(s) of incident
3. Evaluation of Available work practices

The target of the section two of the questionnaire was identify causes of SB incidents. The identified factors of SB incidents which were collected during literature survey were elaborated as a checklist. Respondents have to select validity of each factor to the incident occurred at their factory. They had given opportunity to

express their degree of agreement according to given scale. The rating scale has 1-5 intensity.

Section three of the questionnaire was used to evaluate current work practices. It was focused to identify level of available hazard control measures. Close – ended type questions were given.

3.4.4 Sampling

According to Tan (2002) 'population' is the set of all elements of interest. A 'sample element' is a member of this population. The term sample can describe as "a specimen or part of a whole (population), which is drawn to show what the rest is like" (Naoum, 2013). A sample is either selected randomly or non-randomly.

In random or probability sampling all the individuals in the population have equal chance of selection. But in non-random sampling selection is depend on researcher's personal view point and the purpose of research. All the individuals in the population do not have equal chance of selection. Therefore, it is not sufficient to take clear idea about total population.

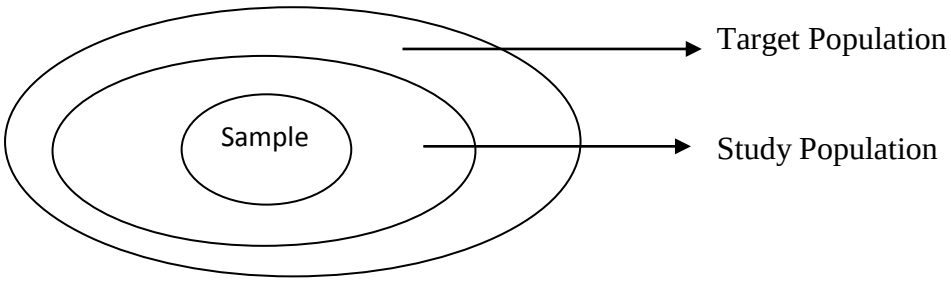


Figure 3.3: Sample and Population

This study was focused to control hazards related to steam boilers used in medium scale manufacturing industries in Sri Lanka. Hence it is necessary to identify reasons for SB related hazards, the effectiveness of current work practices and give suggestions to improve hazard prevention methods. Therefore, random or probability sampling method was used in this research.

According to the current legal requirement manufacturing industries should register in ISD of Department of Labour. Most of these industries are medium scale. Further details of SB incidents reported in those plants should be informed to the same division. Therefore, those registered factories can be divided into two groups. They are as medium scale factories without SB incidents and medium scale factories with SB incidents. In this study those data were used to select sample.

There were hundred and twenty (120) manufacturing industries were selected for questionnaire survey. Among them sixty factories were randomly selected from registered medium scale factories which had SB incidents. SB related incidents were not reported from other sixty factories. Those were randomly selected from registered factories which were identified as medium scale factories without SB incidents. Finalized questionnaire were distributed among Factory Manager of each selected factory. Their answers were collected within two weeks period.

3.4.5 Expert interview

Five experts in the field of OSH were interview. These experts were selected from Industrial Safety Division and Occupational Hygiene Division of Department of Labour Sri Lanka. Table 3.1 shows the details of experts. The interview guide line was prepared based on the findings of literature survey and the questionnaire survey. The intention of interview was focused to refine literature findings regarding SB hazards, SB failures and find improvements and new suggestions to the SB operation and manufacturing processes. Open and closed – ended questions were used in the semi structured interview. Interview findings were used to identify hazards and hazard causing factors and propose strategies to enhance SB operation procedure and SB manufacturing procedure (objectives 4 & 5).

Table 3.1: Experts profile

No	Expert Name	Experience in OSH field-years	Relevant Authority
1	Expert A	25	Industrial safety Division , Department of Labour
2	Expert B	27	Industrial safety Division , Department of Labour
3	Expert C	25	Industrial safety Division , Department of Labour
4	Expert D	20	Occupational Hygiene Division, Department of Labour
5	Expert E	15	Authorized Pressure Vessel Inspector, Department of Labour

3.5 Data Analysis

Questionnaire results were analyzed using graphical and statistical methods. Graphical method was used to identify reported hazards; identify incident reported manufacturing industries and the effectiveness of current practices.

To find out the causes of SB related hazards, Relative importance Index method was applied and the causes of SB related incidents were ranked to identify the critical factors. The relative importance index value rangers from 0 to 1

Relative Importance Index (RII) = $\sum W_n / AN$

- W_n – Weighting to each factor by the respondent
- A- Highest Weight-(in this study =5)
- N-Total Number of samples (in this study-60)

3.6 Summary

Proper research design is important to achieve objectives of a research study. Research philosophy is the most outer layer of the design. In this study Pragmatism

Philosophy was applied. Mixed Research approach with both qualitative and quantitative methods were used to obtain better results. Method of Data collection and data analysis were included under research techniques. Both primary and secondary data were collected. Questionnaire survey and expert interview were used to collect primary data. One hundred and twenty factories were selected randomly from the secondary data available at the ISD. Sample included both factories with SB related incidents and factories without SB related incidents. Graphical, statistical and descriptive methods were applied to obtain results.

Chapter 04

RESEARCH FINDINGS AND DATA ANALYSIS

4.1 Introduction

The purpose of this chapter is to summaries, analysis and explains the data collected through the research process**.**

Data were collected through detailed questionnaire survey and expert interview. Those findings were analyzed to achieve the objectives of the research study.

4.2 Respondent rate and the characteristic of the sample

Totally 120 factories were selected randomly in this research study. They were divided into two main sections as factories with steam boiler related incidents and factories without steam boiler related incidents. Sixty (60) factories were selected randomly from each group. Those factory details were obtained from the secondary data available in the Industrial Safety Division of the Department of Labour.

The questionnaire was forwarded to the relevant Factory Manager. Answer sheet was collected back through District Factory Inspecting Engineers office of each area. Therefore, the response was 100%.

4.3 Steam Boiler related Hazards

The first objective of this research study was identifying steam boiler related hazards. According to the literature survey of this study five types of SB related hazards were found in manufacturing industries. These were identified as chemical, physical, biological, Ergonomic and psychosocial and accidental hazards. Further many sources and situations which were identified as hazards, were found under those types. Expert interviews were conducted with selected experts in the research were used to refine those literature findings further. Finally, those results were summarized as Table 4.1.

Table 4.1 Steam Boiler Related Hazards

Type of hazard	Hazard
Physical Hazards	• Expose to excessive continuous noise levels • Prolong work at high temperature
Chemical Hazards	• Exposure to vanadium dust and Asbestos during maintenance work • Exposure to Chemicals used as additives to SB water • Exposure to respirable fly ash • Burning of high Sulfur fuels hence contact with Sulfur Dioxide and other harmful gases.
Ergonomic and Psychosocial Hazards	• Physical work in noisy and warm work environment. • Wrong posture • Dissatisfaction at work
Biological Hazards	• Presence of insects inside the Boiler room • Development of fungi and grow of Bacteria
Accidental Hazards	• Fuel leaks • Steam leakages • Contact with hot water and hot surfaces • Explosions as a result of Failure of structural components • Slips and falls

4.4 Causes of Steam Boiler Related Incidents

Various researchers found many reasons for steam boiler related hazards.

According to the literature survey of this research, unsafe conditions and unsafe actions are the main reasons for SB failures. As those findings, SB failures create hazards in a work place. Expert interview with selected experts were used to clarify

those findings. Thereafter followings were identified as reasons for SB failures and hazards.

Table 4.2 Unsafe Actions and Unsafe Conditions Details

	Unsafe Action / Unsafe Condition	Reason for Steam Boiler failures and hazards
1	Steam Boiler Manufacturing	1. Faulty design 2. Defects of material 3. Fabrication Error 4. Improper installation
2	Steam Boiler operation	1. safety valve /pressure gauge not working 2. Low water condition 3. Steam leakage 4. Fuel leakage
3	Behavior of SB staff	1. Operator errors 2. Operate without SB attending certificate 3. Use chemicals without PPE 4. Work without PPE in higher noise 5. Prolonged work at high temperatures 6. Unsafe Work at height
4	Steam Boiler Inspection	1. Failure to inspect during regular periods. 2. Under Investigation
5	Steam Boiler Maintenance	1. Poor maintenance 2. Unsafe modifications or alternations

Those literature findings were used to prepare questionnaire and checked the applicability of these facts in actual incidents.

The questionnaire was given to sixty (60) randomly selected factories with reportable SB incidents. Graphical method, Relative Importance Index and Ranking methods were used to analysis the results obtained in the questionnaire.

4.4.1 Types of Reported Steam Boiler Related Incidents

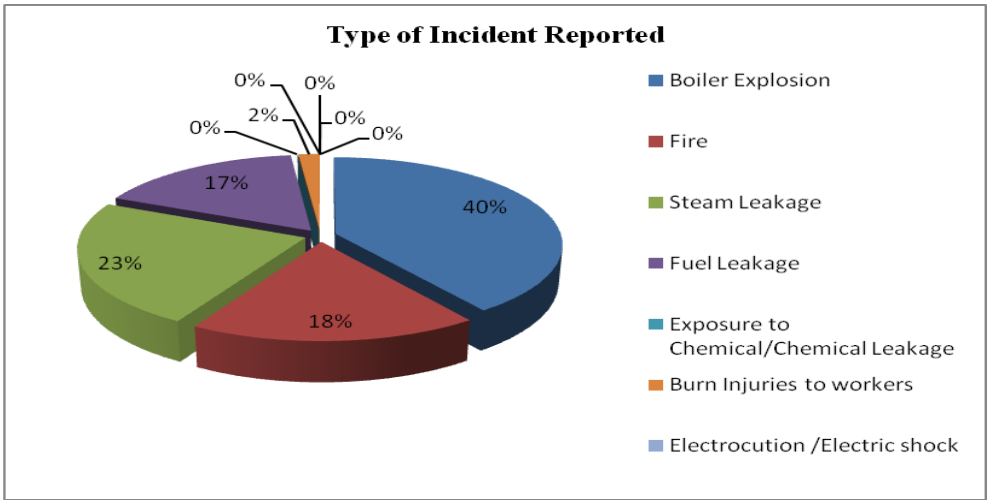


Figure 4.1: Types of Steam Boiler Related Reported Incidents

According to the questionnaire results 40 % of incidents were identified as Steam boiler explosions. Further 23% percentage of steam leakages was reported. Fuel leakages and fires are other main incidents which were reported in manufacturing industries. Only 2% of burn injuries were found. As previous details all these incidents can identified as accidental type hazards. All other incident types such as expose to chemical or chemical leakage, expose to higher noise, electrocution was not reported. Chemical, physical, biological and ergonomic and psychosocial type hazards were not reported in selected set of manufacturing industries.

4.4.2 Types of Manufacturing Industries

As figure 4.2 most of the SB related incidents were reprted in rice mills, deciated coconut mills, rubber factories and tea factories. Few other incidents were reported in food and beverage industry and sugar factory. The highest number 34% of SB

related incidents were reported in Rice Mills. Other heavy production type manufacturing industries had only 3% of incidents..

In most of these industries, human involvement is very high. Further these types of factories spread around the country. Therefore control measures should be taken to prevent SB related incidents.

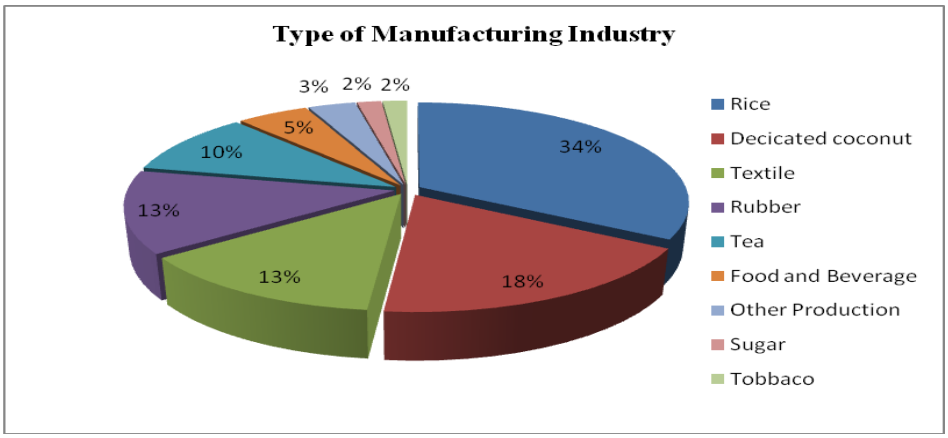


Figure 4.2: Type of Manufacturing Industry

4.4.3 Causes of Steam Boiler Related Incidents

The questionnaire results were further analyzed and "Relative Importance Index" value was found in each case. Then ranking was done.

According to the below Table 4.3 human activities mainly caused to the SB related incidents. Poor SB maintenance was identified as main reason of the reported incidents. Operator errors also had critical impact. Operate without SB attending certificate or operate the SB without required skills was another reason for SB related incidents. Many other human errors such as work with chemicals without PPE, exposure to higher noise without protection, unsafe work at height, caused to the SB related incidents.

Steam boiler manufacturing errors such as Malfunctioning of important SB parts, steam and fuel distribution system defects, defects of construction materials, fabrication errors such as welding defects, initial design failures, wrong SB installation, unsafe modifications also create the hazardous SB incidents.

Table 4.3 Ranking of causes of hazardous Incidents

	Cause of hazardous Incident	Relative Importance Index	RANK
1	Poor maintenance	0.5767	1
2	Operator errors	0.3933	2
3	Steam leakage	0.3866	3
4	Fuel leakage	0.3333	4
5	Fabrication Error	0.3200	5
6	Low water condition	0.3133	6
7	operate without boiler attending certificate	0.3033	7
8	Failure to inspect during regular periods	0.2833	8
9	Faulty design	0.2533	9
10	Improper Installation	0.2367	10
11	Prolonged work at high temperatures	0.2333	11
12	Safety valve not working	0.2300	12
13	Defects of Materials	0.2267	13
14	Pressure Gauge not working	0.2233	14
15	Unsafe modifications	0.2200	15
16	Use chemicals without PPE	0.2133	16
17	Exposure to fly Ash	0.2100	17
18	Unsafe Work at height	0.2067	18
19	Exposure to Higher Noise level	0.2033	19
20	Vibration of Boiler Parts	0.2000	20

Normally, operation procedure of a machine is also important to ensure safe work place. During SB operation, good procedures minimize the relevant hazardous incidents. According to the questionnaire results of this study steam boilers had operated without regular inspections, had several failures. Therefore, hazardous

situations were reported in those cases. As example many hazardous incidents were reported as a result of low water condition.

According to the above details most of the reported SB related incidents were accidental type hazards.

Those hazards were mainly generated as result of poor maintenance and other unsafe human actions. Initial SB construction and method/ place of machine install were also caused to few incidents. Further Bad operation methods have significantr effect to the safety at work.

4.5 Current Work Practices

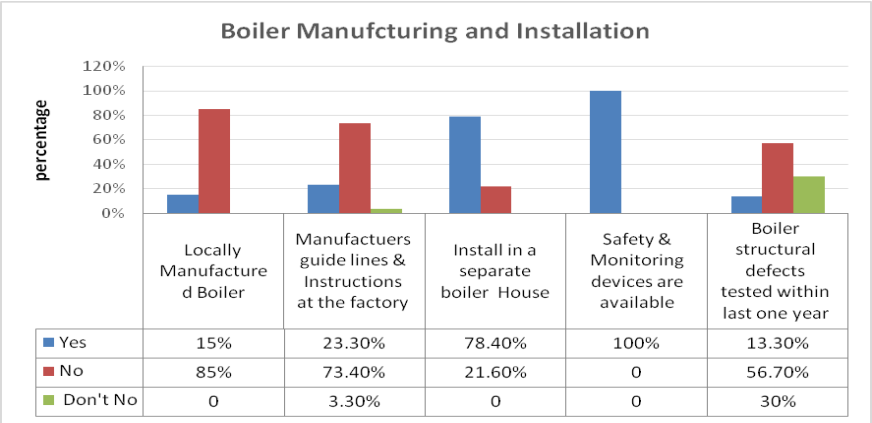
The third objective of this research is to identify the level of available control measures to minimize SB related hazards. According to the literature survey of this research study safe work practices help to control and minimize SB hazards. Therefore, SB manufacturing and installing, operation procedures, operator behavior, third party SB inspection and SB maintenance activities were checked through questionnaire.

The questionnaire was given to randomly select sixty factories where SB related incidents were not reported. Same questionnaire was given to another randomly select sixty factories with SB related incidents. Those results were used to identify the successfulness of available work practices.

4.5.1 Steam Boiler manufacturing and Installation

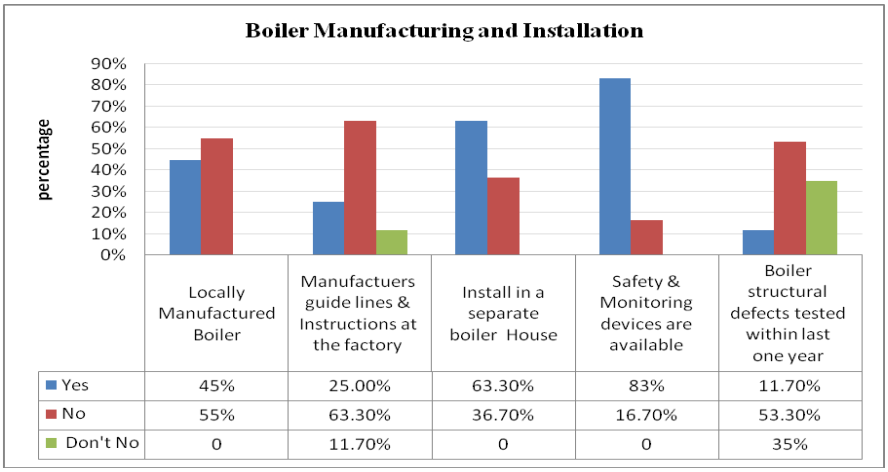
According to the figure 4.3(a) and figure 4.3(b) SB related incidents were not reported under safe situations. As example when safety and monitoring devices available (figure 4.3(a)), incidents were not found. On the other hand, 16.7% of factories were not used these safety monitoring devices for their steam boilers. Steam Boiler related incidents were found in that factories. Structural defects testing, referring manufacturer guidelines and instructions, is important to ensure safe work place at a SB. In both situations less attention was given to these factors. Only

23.30% and 25% factories have manufacturers guide lines and instructions with them.



	Locally Manufactured Boiler	Manufactuers guide lines & Instructions at the factory	Install in a separate boiler House	Safety & Monitoring devices are available	Boiler structural defects tested within last one year
Yes	15%	23.30%	78.40%	100%	13.30%
No	85%	73.40%	21.60%	0	56.70%
Don't No	0	3.30%	0	0	30%

Figure 4.3(a) Steam Boiler manufacturing and installing details (Factories without incidents)



	Locally Manufactured Boiler	Manufactuers guide lines & Instructions at the factory	Install in a separate boiler House	Safety & Monitoring devices are available	Boiler structural defects tested within last one year
Yes	45%	25.00%	63.30%	83%	11.70%
No	55%	63.30%	36.70%	16.70%	53.30%
Don't No	0	11.70%	0	0	35%

Figure 4.3(b) Steam Boiler manufacturing and installing details (Factories with incidents)

4.5.2 Steam Boiler Operator

Human activities and attitudes highly affect the safety of their work. Therefore, Steam Boiler operator behavior, experience and skills are very important to ensure safe work place at a SB. According to the current law it is necessary to recruit well trained separate worker with necessary qualifications as a Steam boiler operator.

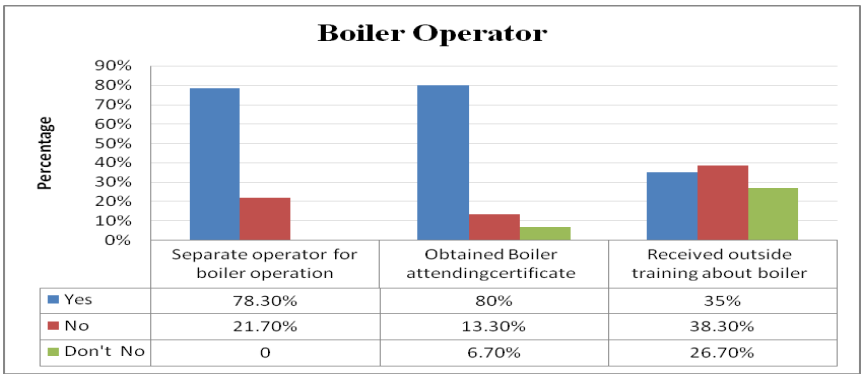


Figure 4.4(a) Steam Boiler operator details (Factories without incidents)

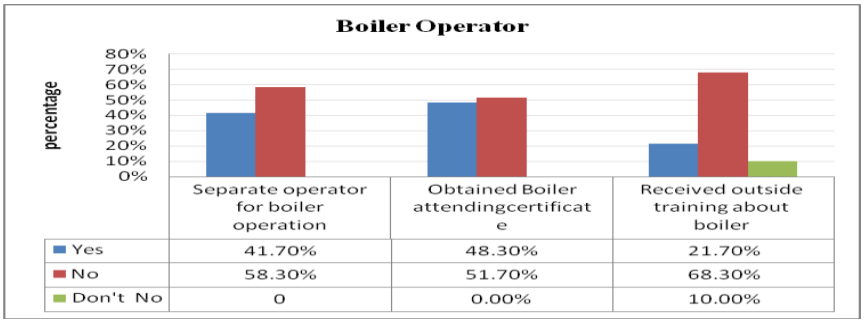


Figure 4.4(b) Steam Boiler operator details (Factories with incidents)

If we consider the results of this research study, as figure 4.4 (a) 78.3% of factories have separate operator for SB operation. 80% of SB operators have SB operation certificate. 35% of them received outsource training. Therefore, SB related incidents were not reported at their factories. When we consider the figure 4.4(b) 41.7% of factories have separate operator for SB operation. 48.3% of SB operators have SB operation certificate. 21.7% of them received outsource training. These numbers are relatively lower than the details of figure 4.4(a). So, SB related incidents were reported at those factories. Therefore, human skill and behavior is an important factor to control SB related incidents.

4.5.3 Steam Boiler operation

Workers unsafe actions make a work place unsafe to work. Therefore, SB operation procedure, third party safety inspections and maintenance procedures have higher impact on work place safety.

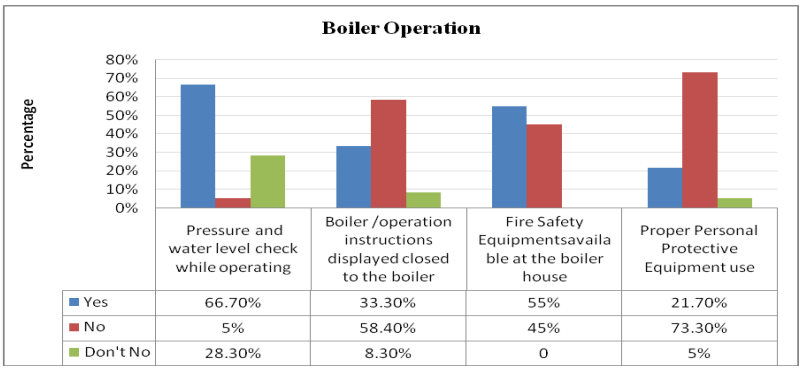


Figure 4.5(a) Steam Boiler operation details (Factories without incidents)

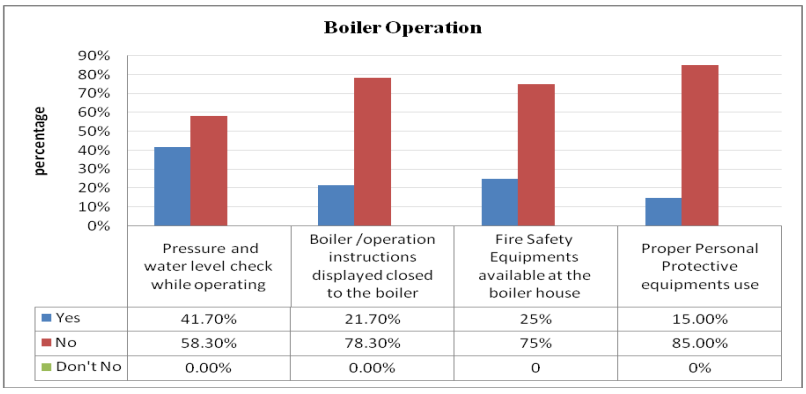


Figure 4.5(b) Steam Boiler operation details (Factories with incidents)

According to the figure 4.5(a) and Figure 4.5(b), good work practices were not properly applied in steam boiler operation. When consider the factories where incidents occurred only 15% use proper Personal Protective Equipments. Only 25% factories have installed fire safety equipments at SB house. Most important water level and pressure checking were not followed by 58.3%. When consider the factories without incidents they have relatively higher percentages.

Although SB related incidents were not reported satisfactory results were not found in other set of factories. In that case 73.3% of factory workers not use proper Personal Protective Equipments. Some don't have any idea about these good work practices. As example 28.3% said they don't know whether pressure and water level checking are doing or not doing while SB operating.

4.5.4 Steam Boiler Inspection

As Literature survey of this research study, regular third-party SB inspection is useful to identify SB defects and other system faults. After this inspection it is

necessary to repair and fix the identified system faults. Figure 4.6 (a) and Figure 4.6(b) provide the details that have found in this research study about third party SB inspection.

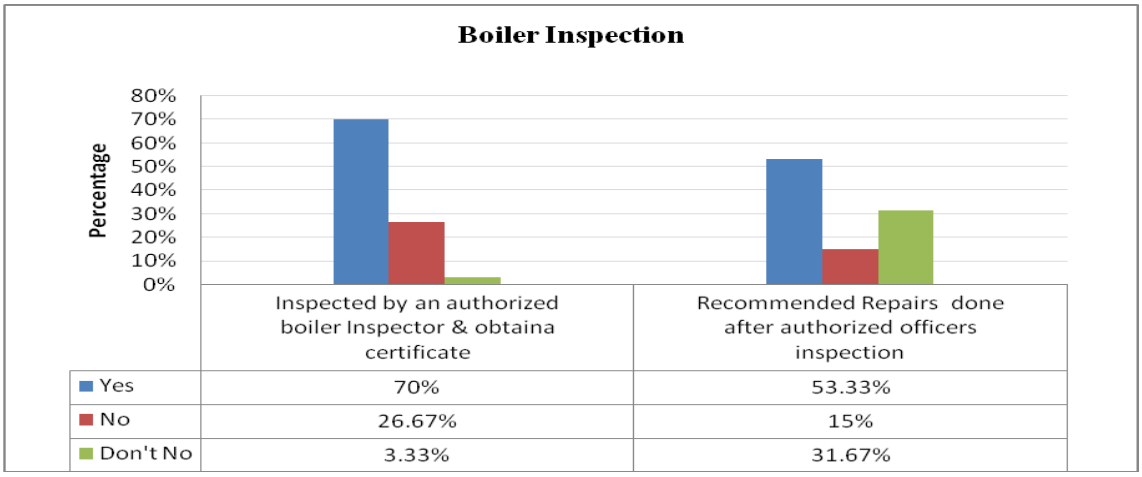


Figure 4.6(a) Steam Boiler inspection details (Factories without incidents)

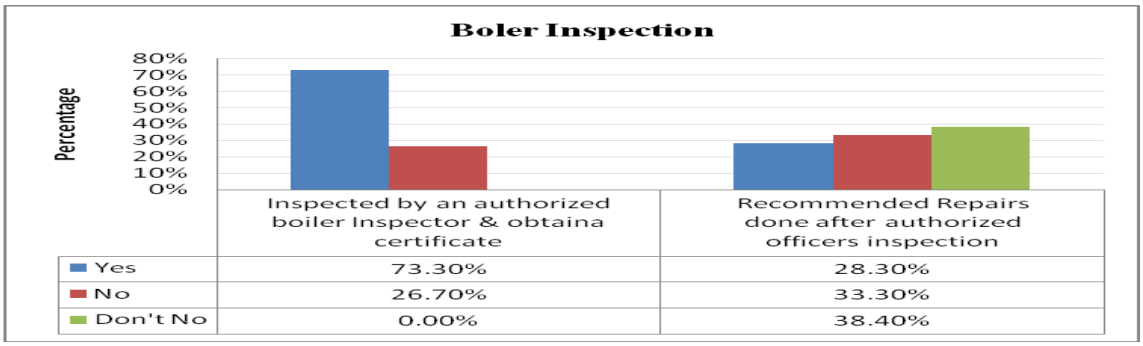


Figure 4.6(b) Steam Boiler inspection details (Factories with incidents)

In both cases about 70% factories have done regular third- party SB inspections. But as Figure 4.6(a) recommended repairs were done in 53.33% factories included in the first group. But it was less at "other group" [figure 4.6(b)]. Only 28.3% factories have completed the recommended repairs. This type of negligence creates SB incidents in second group of factories.

4.5.5 Steam Boiler Maintenance

As other machineries and equipments steam boilers also need to maintain properly. Otherwise unsafe condition creates hazards at a SB house. These maintenance

activities should be done properly by trained mechanic. If not, those activities can also create hazardous situation at the work place.

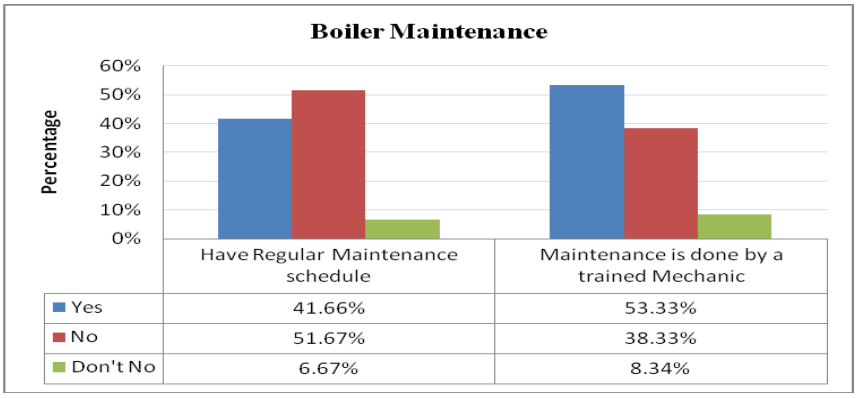


Figure 4.7(a) Steam Boiler maintenance details (Factories without incidents)

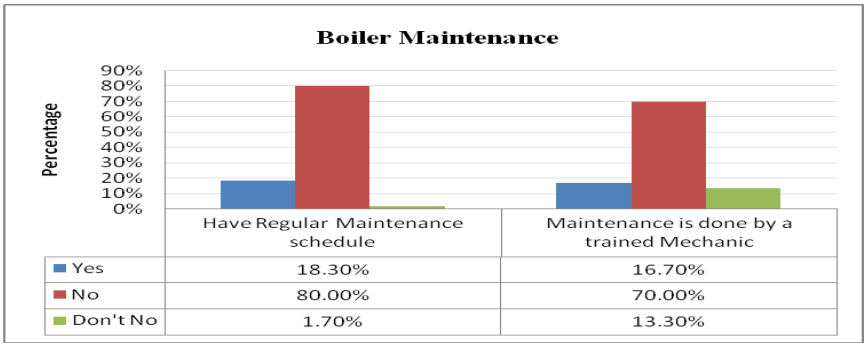


Figure 4.7(b) Steam Boiler maintenance details (Factories with incidents)

According to the figure 4.7(b) 80% of factories where boiler incidents reported do not have regular maintenance programme. Further in this group of factories only 16.7% factories were recruited trained mechanic for their maintenance work. This less attention creates dangerous situation at these factories.

Although boiler related incidents were not reported, satisfactory maintenance schedules were not found in other set of factories figure 4.7(a). In that case 51.67% of factories not use proper maintenance schedule. But 51.33% of factories take the service of trained worker. Therefore, maintenance work should further increase to control SB incidents and all dangerous situations.

4.6 Enhance standard of Steam boiler Operation and Manufacturing procedures

According to the Literature survey and field survey most of the SB related hazards originate as a result of SB structural components, accessory parts or work practices of the SB attending staff.

In this research five OSH Experts were interviewed to identify SB related hazards, causes of hazards and SB failures. Further they were interview to collect their opinions regarding safe SB operation and SB manufacturing. A semi-structured interview was conducted by using both open ended and close ended questions. The interview findings were analyzed through detail analysis method.

Finally, those data were used to propose strategies to enhance the current manufacturing and operation procedures. (Objectives 4 and 5)

4.6.1 Expert suggestions for improve Steam Boiler operation procedure.

Following details were obtained during the interview process.

Suggestion 1: Steam Boiler Registration

Steam Boiler registration was suggested by all experts. Expert "A" said "Steam Boiler registration should include as legal requirement as annual motor vehicle registration". Expert "B" stated "authorized inspection reports, maintenance records, SB attendance certificates should provide as supportive documents during this registration". He mentioned "that will encourage SB owners to follow safe SB operation requirements". Expert "E" and Expert "D" mentioned "this registration will help to identify details about local manufactured and imported steam boilers". Expert "C" said "Steam boiler registration details can use to collect critical information required for national level rules, regulations and policy preparing relevant to the safe SB operation, maintenance and repair".

Suggestion 02 : Strengthening the existing legal frame work

Industrial Safety Division of Department of Labour is responsible to enforce the legal requirements related to the SB operations. Expert "A" mentioned "Resources of Industrial Safety Division of the Department of Labour need to be increased". According to him, No of Factory Inspection Engineers and no of inspections should increase to enforce laws and regulations. Expert "B" of the same department explained, "The new rules and regulations should be introduced to strengthen the relevant provisions of the Factories Ordinance". Further all experts stated that increasing fines for contravention of related sections of the Factories Ordinance, can lead to increase employees and employers attention to safe SB operation.

Suggestion 03 : Awareness among employer and employee

All experts mentioned the importance of Safety Awareness Programmes and other safety awareness activities. Expert "A" mentioned "these awareness programmes should include knowledge about SB hazards and instructions of safe operation. Expert "C" from the same department suggested, district level and organizational level awareness programmes for small and medium scale industries such as rice mills. Further he mentioned "these awareness Programmes at district level and organizational level can used to provide knowledge on related legal requirements". Expert "D" said "Most of the Occupational diseases and health impacts can prevent with proper work practices. But most employees and employers do not know when and where these diseases originated". So, he suggested knowledge sharing on possible health impacts of SB operation. Expert "E" mentioned "advertisements in public media such as news papers can be used to share relevant information on laws regulations and standards. It will help employers/employees and other interesting parties to obtain valuable information".

Suggestion 04 : Employing Qualified Steam boiler operators in organizations.

All experts mentioned the importance of the SB operators role when try to establish hazard control workplace. Expert "C" stated "Some Organizations employing any person as a SB operator. Sometimes in small rice mills, mill owner is the SB operator. So, it is necessary to strictly follow SB attending certification process

according to the current legal requirements". As current SB regulations authorized inspectors issue SB attending certificate to the SB operator. Required qualifications were published under current SB regulations. Further he should send a copy of that certificate to Chief Factory Inspecting Engineer. Expert "B" mentioned "It is the responsibility of SB authorized officer. He should issue SB operating certificate only to a qualified person". Issuing these competent certificates from ISD was another suggestion Expert "D" said "some other countries have separate authorities or sub units under Ministry of Labour for certification process. ISD of DOL needs more technical staff and other resources to implement this in Sri Lanka".

Suggestion 05 : Periodical Steam boiler Inspection by a qualified authorized officer

According to the all experts periodic SB inspections help to identify structural and operational failures which cause to generate SB hazards. Expert "A" mentioned the need of appoint more authorized inspectors. He said "Steam Boiler Inspection is a legal requirement in Sri Lanka, but the number of authorized inspectors is insufficient to cover all manufacturing industries in the country". Expert "B" explained the requirement of monitor the work of these SB authorized inspectors. Expert "E" and Expert "C" stated most of the small and medium level industries not aware about the importance of this periodic inspection of a SB. So as monitoring crew, Factory Inspecting Engineers of the Department of Labour have responsibility to improve awareness among them.

Suggestion 06 Appoint Qualified authorized Steam boiler inspection officers.

Steam Boiler Inspectors performance is very important to identify functional and structural failures of a SB. All experts mentioned the need of inspections. They all said "these inspections should be done by qualified authorized inspection officers". Expert 'B' stated "sometimes we have problems about the quality of their inspections. It is good to meet these inspection officers periodically. These discussions help to identify their weakness and problems". Expert 'C' and 'E' mentioned the necessity of provide specific training periodically through technical Experts. Expert 'A' suggested establish a new sub section such as "National Board of Boiler and Pressure vessel

Inspectors-USA" under Industrial safety Division of Department of Labour Sri Lanka. He said "It is easy to manage their work properly through this type of separate section. Expert 'D' said "All inspections agencies and inspectors must hold the qualified certificate issued by Department of Labour. They all should renew their certification annually".

Suggestion 07 : Provide technical support to Steam boiler maintenance and repair work.

According to the all experts, regular maintenance is important to ensure proper function of SB controls, valves and other attachments. Expert 'E' mentioned "Resources at the Industrial Safety Division of the department of Labour should be increased and the officers should give opportunity to upgrade knowledge in the relevant field. Then these Engineers can help to provide good technical support to the industry". According to the Expert 'C' technical Bodies such as Institute of Engineers Sri Lanka and Sri Lanak Standard Institution can provide necessary technical support to the manufacturing industry Expert 'A' said "steam boiler repairs and alterations must meet the accepted industry quality standards for pressure vessel repair". It is essential to conduct alternations or repairs of steam boilers only by competent persons. Expert 'D' mentioned the need of recruit competent person as SB mechanic. According to Expert 'B' Most of the companies do not have periodic maintenance schedule. He Said "They only give priority to production activities. Therefore, they are not worrying about machine maintenance until running breakdowns".

Suggestion 08 : Start Steam boiler related job Oriented training courses at Vocational Training Centers and Technical colleges.

Expert 'E' mentioned "This will help to recruit more technically eligible persons as SB operators and maintenance members". Expert 'C' said "Through this type of courses public will more aware about safe SB operation". Expert 'D' stated "It is easy to share knowledge, change attitudes and behavior pattern through this type of training programmes. According to Expert 'A' these courses can use to train current SB operators and maintenance workers. He said "these training courses should open

not only to beginners but also those who are already work in the relevant field". Expert 'B' said "the course curriculum should include steam boiler safety and relevant legal requirements".

Suggestion 09 : Improve Fire safety process at the factory

Fire is a possible hazard at a SB house. Expert 'A' said "SB attending staff should know about emergency evaluation procedures". Expert 'C' mentioned "It is important to ensure proper functioning of electrical installations in the SB room. Malfunctioning of these instruments may create fire hazard". According to Expert 'B' fuel and other addictives should store properly. He said "Leakages of these liquids create unsafe work environment. If these are flammable fires are possible to occur". According to Expert 'D' emergency reporting facilities should maintain at the SB house.

Suggestion 10 : Use Chemical Hazards Preventive methods.

Fuel, water additives and asbestos which use for SB operation have health impact. So, Expert 'A' mentioned "It is essential to use protective clothing, correct size and type of face masks and safety glasses when working with feed water chemicals". Expert 'C' said "These chemicals and fuels should store properly. Containers that contain hazardous materials must be labeled, tagged and marked". Expert 'D' stated "SB workers should know emergency treatment procedures. Suitable first-aid facilities should maintain at the factory".

Suggestion 11 : Accident Reporting, Record Keeping and Communication between shift workers.

Expert 'C' mentioned the need of accident and incident reporting and record keeping. He said " Accident Reporting help to prevent reoccurrence same incident. It provides necessary information to identify faults and correct them". Expert 'B' mentioned "It is better to use SB- log book to enter all details about SB installation, alternatives and maintenance". Expert 'A' stated "Some SB accidents report as a result of poor communication. When SB is operated by shift workers, necessary information should pass between them".

Table 4.4 Expert suggestions for improve Steam Boiler operation procedure

Suggestion	Related Activities
Steam Boiler Registration	1. Annual Steam Boiler registration 2. Use inspection reports, maintenance records as supportive documents during registration
Strengthening the existing legal frame work	1. Introduce new rules and regulations 2. Increase fines
Awareness among employers and employees	1. District and organizational level awareness programmes for small and medium level industries 2. Awareness about SB related Occupational diseases 3. Awareness through public media
Employing qualified steam Boiler operators	1. Improve SB attending certification process 2. Issuing competent certificates from ISD
Periodical Steam boiler Inspection by a qualified authorized officer	1. Appoint more authorized SB inspectors 2. Monitor the work of inspection officers 3. Inform industry people about importance of periodic inspections
Appoint Qualified authorized Steam boiler inspection officers	1. Provide specific training to inspection officers 2. Annual renewal of inspection authority 3. Establish section to manage their work
Provide Technical support to Steam boiler maintenance and repair work.	1. Periodic maintenance under schedule 2. Provide technical support to industries 3. Appoint competent workers for maintenance 4. Repairs done according to the quality standards
Start SB related training courses at Vocational Training Centers and Technical colleges.	1. Train current workers, operators and maintenance workers 2. New coursers for beginners 3. Add SB safety and relevant rules to the cause curriculum
Improve Fire safety process at the factory	1. Improve knowledge of emergency evacuation procedures 2. Proper electrical installations 3. Fuel and additives store properly
Use Chemical Hazards Preventive methods	1. Chemicals and fuels store properly 2. Use PPE during work. 3. Knowledge sharing about emergency treatment
Accident Reporting, Record Keeping and Communication between shift workers.	1. Use a SB log book 2. Proper method to communicate between shift workers 3. Accident /incident recording system

4.6.2 Expert suggestions for improve Steam boiler manufacturing procedure.

Suggestion 1: Registration of Steam Boiler manufacturers

Steam Boiler manufacturers have to register their industries under Business registration rules. Expert "C" said "a method should initiate to register all Steam boiler manufacturing factories under Industrial Safety division". Then it is easy to collect information and provide necessary guidance to their activities. Expert "E" mentioned "this registration is helped to maintain good relationship between state and private sector. Government can help manufacturers to obtain necessary technical support from local or global experts/ expert organizations".

Suggestion 2: Steam Boiler Standards

Expert "B" mentioned the requirement of implement the steam boiler standards as several other countries. He said "the standards development process which combines with experience of manufacturers, enforcement authorities and owners/users help to prepare more suitable standards to local industries." Expert "A" said placing control on the design, materials and fabrication methods is helped to achieve quality of the final product. Steam Boiler standards can use for this". Expert "C" mentioned "this standardization helps to provide proper safe accessories to a SB. Under standardization those items should approve by authorized authority before use them". Expert "E" stated "Sri Lanka Standard Institute already prepared these standards includes SB manufacturing requirements and test methods. Now need well organized procedure to use and practice those standards for better performance".

Suggestion 3: Technical support for Local manufactures

Expert "A' mentioned "sometimes small and medium level industries use locally manufactured Steam boilers. Those steam boilers have poor qualities and easily create hazards situation. These manufactures need technical support". Expert "B" and "C" said "technical organizations such as The Institute of Engineers Sri Lanka, Engineering Faculties of our university system, Technical Institutions can provide specialist technical support". Expert "D" stated "conducting training programmes and awareness seminars for SB manufacturers will lead to improve their knowledge

on standard manufacturing and installing requirements". Expert "E" said short term skill development courses will help to create good welders and testing staff. Technical education should provide this type of courses according to the requirement of the country".

Suggestion 4: Control on Import Steam boilers, materials and accessories.

Expert "C' mentioned "Most of the steam boilers used in manufacturing industries were imported from other countries. Sometimes these are old and used equipments. So, it is necessary to implement method to identify those equipments". Expert "A" suggested "a safety quality licensing certificate should obtain for every imported steam boiler before industrial use". Then it helps to reject unsafe steam boilers. Expert "B" said "the relevant legal provisions should strengthen with necessary regulations". Expert "D" mentioned "these control measures should also apply to all materials and accessories which are imported for steam boiler construction". Expert "E" stated "safety and quality licensing certificate should issue after inspection of qualified technical team. They should employees or certified inspectors of Industrial Safety Division of Department of Labour".

Suggestion 5: Authorized inspections during manufacturing process

All experts mentioned the importance of authorized inspections during manufacturing process. They said "All these inspections will help to prepare safe SB for end-user". Expert 'A' mentioned "Organized inspections are necessary to monitor steam boiler manufacturing activities and correct potential problems through an early identification". According to Expert 'C' and 'E', third party inspectors can involve these inspections. They said "all inspection agencies and inspectors must hold the qualified certificate issued by the Industrial Safety division of Department of Labour". Steam Boiler accessory parts and Manufacturing materials have significant effect on safety of a SB. Expert "B" stated "Manufacturing materials and SB accessories, should be audited, approved and certified by a qualified inspector prior to use in the manufacturing process.

Suggestion 6: Strengthen the relevant Rules and Regulations

According to the Factories Ordinance No 45 of 1942, every part of a steam boiler should construct properly with proper materials. Expert 'A' explained the importance of strengthen this legal frame work. He said "it is necessary to add more details to the Factories Ordinance regarding SB manufacturing. Then it is possible to legally control the process". Expert 'B' pointed out the need of new regulations. He mentioned regulations should make to control SB manufacturing materials, test requirements, inspection requirements, etc. Expert 'D' said "we should pay attention on health of the workers involve in SB manufacturing. They expose to dust and other harmful substances during SB manufacturing. Rules and regulations should introduce to improve their safety". The current trend in the industry is assigned extra work to the SB inspectors. They involve in maintenance and inspection of other machines. Expert 'C' and 'D' said rules and regulations should strengthen to legally control the SB inspection activities. That will help to stop inadequate or inaccurate approvals and certification".

Table 4.5 Expert suggestions for improve Steam Boiler manufacturing procedure

Suggestion	Related Activities
Steam Boiler Registration	1. Registration of all SB Manufactures at ISD 2. Collect necessary details and provide technical support
Introduce steam boiler standards	1. Introduce new standards and methods to practice 2. Placing control on design, materials, accessories and fabrication methods
Technical support for local manufacturers	1. Technical support through technical organizations and 2. Awareness programmes about SB manufacturing activities 3. Short term skill development trainings
Control on import SB, material and accessories,	1. Method to identify old and used imported SB 2. Quality licensing certificate for every imported SB 3. Strengthen the relevant rules and regulations
Inspection by a qualified authorized officer during manufacturing process	1. Appoint third party authorized SB inspectors for inspections 2. Manufacturing materials and accessories should be audited and approved
Strengthen the relevant rules and regulations	1. New rules and regulations to Legally Control on manufacturing materials, test requirements and inspections

4.7 Summary

Most of the SB failures occur as a result of unsafe conditions and unsafe actions. Further these failures create dangerous incidents in the work place. According to study findings most of these incidents have identified as boiler explosions, fire at work place, burn injuries, steam leakage or fuel leakage. All these are considered as accidental hazards.

According to ILO classification Steam Boiler related hazards can be classified as Accidental hazards, Chemical hazards, Physical hazards, Ergonomic, Psychosocial Organizational hazards and Biological hazards. Among them accidental hazards were commonly reported in manufacturing industries in Sri Lanka. Unsafe conditions and unsafe actions which had created dangerous SB failures cause to these accidental hazards.

Current SB operation procedures, operator behavior and SB manufacturing procedure need further improvements. So, experts have given several suggestions to upgrade those procedures.

Chapter 05

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The first objective of the research study is to identify Steam Boiler (SB) related hazards. According to the literature survey, ILO has classified SB related hazards as Accidental hazards, Chemical hazards, Physical hazards, Ergonomic, Psychosocial, Organizational hazards and Biological hazards. These types of hazards had been classified as the Table 4.1.

According to this study results most of the SB related incidents reported in Sri Lanka were SB structural explosions, steam leakages, fuel leakages, contact with hot surface and hot water. These were identified as Accidental hazards. Other hazard types were not found among reported incidents. Therefore, accidental hazards are the most common steam boiler hazard type in manufacturing industries in Sri Lanka.

These accidental hazard type incidents were common among industries such as rice mills, desiccated coconut mills, tea factories, rubber factories, textile and Garment Factories. The highest level of hazards percentage 34% had happened in Rice mills. Other production categories had only 2% of reported hazards incidents.

The second objective of this study was to analyse the causes for these hazards. According to the literature survey and data analysis, several factors were found as hazard causing factors. These were mainly identified as unsafe actions and unsafe conditions generated during SB operation and SB manufacturing. This manufacturing and operation procedures include SB manufacturing and installation, SB operation, SB inspection, SB maintenance. Further this study reveals that SB operator behavior has significant effect on proper functioning of SB operation and SB manufacturing.

These activities were further described as, poor maintenance, operator errors, operate without boiler attending certificate, use of chemicals without Personal Protective Equipment, exposure to higher noise, prolong work at higher temperature, exposure

to fly ash and unsafely work at height. Further, manufacturing errors such as material defects, fabrication errors, had also created SB related hazards. All these had direct human error involvement.

According to the results of the study, poor maintenance is the highest-ranking factor which causes the SB incidents in Sri Lanka. Operator errors also have significant effect. Unskilled operators those are working without qualifications are another reason. The study revealed that some incidents reported as a result of fabrication errors of SB. Third party inspection is another important requirement to ensure safety of SB. If it is not conducted regularly in a proper manner then accidental hazards were reported. Therefore, these hazard causing factors should be eliminated or controlled to minimize SB related hazards.

Third objective of this research was to identify weakness and success of current work practices. Work procedures of factories with SB related incidents and factories without SB related incidents were questioned to obtain necessary data. According to that questionnaire data "relatively better work practices" had reported on "No incident Group" For example 78.3% of factories those obtained service of a separate boiler operator fell into "No incident group". But in other group "with incidents" only 41.7% percentage of factories had separate SB operator for SB operation. Therefore, hazardous incidents were reported in that second group. As study results more than fifty percent of factories included in the category of "without incident group" had trained mechanic for maintenance work. But in "with incident" group only 16.7 % factories had trained mechanic for maintenance work. Only 18% percent of these factories performed regular maintenance. In other group it was recorded that as 41.66% percentage. Accidental hazards were not reported in that group.

Most of the factories in both groups have done regular SB inspection. It is a mandatory legal requirement in Sri Lanka. So, it reveals legal influence is an important aspect to control SB related hazards. In both groups most of the workers not use proper Personal Protective Equipments during their work. Fire safety procedures also need to be strengthened in the SB house. Further better outsource

training should be given to SB Operator. These good work practices need further development in both cases.

Finally, suggestions of experts in the field of OSH and study findings were used to achieve fourth and fifth objectives. Fourth and fifth objectives of this study is proposing strategies to enhance standard of steam boiler operation and manufacturing as proposed in the recommendations under 5.2.

5.2 Recommendations

According to the study results of this research, accidental hazards are the most common hazard type in Sri Lanka. These hazards are appearing as Structural failures, fire, steam or fuel leakages, etc. All these have reported in local industries such as rice mills, tea factories, desiccated coconut mills, textile industries, etc. Theses hazards have considerable effect to occupational safety and health of workers. Several steps have already taken to minimize effect of those hazards. But study reveals those steps need further attention.

Experts have given some important suggestions to improve both SB manufacturing and SB operation. So, study is suggested to implement following strategies to improve SB operation and manufacturing.

1. Stablish a new sub section under ISD of DOL Sri Lanka to manage SB related work
2. Registration of Steam Boiler manufacturers and Steam boilers used in Sri Lanka.
3. Implement the Steam Boiler Standards in Sri Lanka
4. Provide Technical support for Local SB manufactures and local manufacturing industries for repair and maintenance work
5. Control on Import Steam boilers, Steam boiler material and other accessories.
6. Authorized inspections during manufacturing process as well as periodical Steam boiler Inspection during SB operation by a qualified authorized officer
7. Strengthen the existing legal frame work

8. Conduct awareness programmes and other awareness activities to improve awareness about SB safety requirements, standards, rules and regulations among employer, employee and public
9. Start SB related training courses at Vocational Training Centers and Technical colleges.
10. Implement good work practices such as fire safety methods, chemical safety methods, and accident recording methods in manufacturing industries.

5.3 Further research

This research was mainly focused to steam boilers used in manufacturing industries in Sri Lanka. But SB is widely used in other sectors such as thermal power generation. So, this study can be carried out for power generation industry. Further this research study was focused to identify hazards in all manufacturing industries in Sri Lanka. But according to the research findings some industries such as rice mills had lot of accidental hazards. Therefore, research study can be carried out to identify further details in a specific industry.

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APPENDIX A
DETAILS REQUESTING LETTER

District Factory Inspecting Engineers Office,
Department of Labour,
Galle.

.....
.....
.....
.....

Sir/ Madam,

Collection of Details of Steam Boiler related Hazardous Incidents

Please be kind enough to provide details of the hazardous Steam boiler accident / incident reported in your factory. Please refer questionnaire guideline and use given format to provide those details. Those details are collecting to use in the research study done by Industrial Safety Division of Department of Labour.

Thank You.

M.H.I.Lakmali,

APPENDIX B
QUESTIONNAIRE GUIDELINE

Questionnaire Guideline

Research

Research on "Effective Control of Hazards Related to Steam Boilers used in Manufacturing Industries in Sri Lanka"

This research is focused to minimize steam boiler accidents and other hazards.

Purpose of the questionnaire

Results of this questionnaire are expected to accomplish following objects of the research.

1. Analysis causes of steam boiler hazards
2. Identify weakness and success of available control measures to minimize steam boiler hazards.

Answer to the questionnaire

- The questionnaire contains three sections. Please provide answers to each section according to the given instructions.
- The questionnaire can be filled by the Factory Manager or safety Manager
- You can use Sinhala or English Languages to provide answers.
- Kindly send the filled questionnaire within two weeks period from this request. Use the stamped envelope sending herewith for return your results.
- For further details, Please Contact Researcher M.H.I.Lakmali (077 9131937)

Confidentially Statement

All collected data will be handled with strict confidentiality. The actual names of the organizations and the respondent details will not be revealed.

APPENDIX C

QUESTIONNAIRE FOR DETAIL COLLECTION

Section A :General Information about Steam Boiler

Please provide necessary details for followings.

(1) Organization name (Optional) …….

(2) Type of Industry …….....

(3) Type of Boiler

(a) Fire tube ☐

(b) Water tube ☐

(c) Packaged type ☐

(4) Country of Manufacturing

(a) Local ☐

(b) Imported ☐

(5) Type of fuel used

(a) Bio mass ☐

(b) Paddy husk ☐

(c) Diesel ☐

(6) Select type of steam boiler related incident reported in your Factory, (if any)

(Boiler explosion / Fire / steam leakage / fuel leakage /exposure to Chemical or Chemical leakage / burn injuries to workers / Electrocution or Electric shock / Exposure to higher noise or vibration / fall and slips at boiler room/ other)

……

….

Section B

Select reason/reasons for the above explained incident which had considerable effect to the incident. Please select (√) your degree of agreement according to the below scale.

Not at all	Fair	Moderate	High	Very High
1	2	3	4	5

	Cause of Incident	**1**	2	3	4	5
01	Faulty design					
02	Defects of Materials					
03	Fabrication Error					
04	Improper Installation					
05	Low water condition					
06	Safety valve not working					
07	pressure Gauge not working					
08	Operator errors					
09	operate without boiler attending certificate					
10	Failure to inspect during regular periods					
11	Poor maintenance					
12	Unsafe modifications					
13	Exposure to Higher Noise level					
14	Prolonged work at high temperature					
15	Vibration of Boiler Parts					
16	Use chemicals without PPE					
17	Exposure to fly Ash					
18	Work at height					
19	Fuel leakage					
20	Steam leakage					

Section C : Available control Measures

Please select most appropriate answer (Yes / No / Don't know) for followings considering your work place.

No 1	Boiler Construction and Installation	Yes	No	Don't know
(i)	Locally Manufactured Boiler			
(ii)	Manufactures guidelines and instructions available at the factory			
(iii)	Install in a separate boiler House			
(iv)	safety and monitoring devices are available (safety valve, Pressure Gauge, low water alarm system)			
(v)	Boiler structure defects tested within last one-year period			

No 2	Boiler Operator	Yes	No	Don't know
(i)	Separate operator for boiler operation			
(ii)	Obtain steam boiler attending certificate			
(iii)	Received outside training about steam boiler and steam boiler operation			

No 3	Boiler Inspection	Yes	No	Don't know
(i)	Inspected by an authorized steam boiler Inspector and obtain a valid certificate			
(ii)	Recommended Repairs have done after authorized officers inspection			

No 4	Boiler Operation	Yes	No	Don't know
(i)	Safety Parameters (Working Pressure/ Water level) check while operating			
(ii)	Boiler operation Instructions displayed close to the boiler			
(iii)	Fire Safety Equipments available at the boiler house			
(iv)	Proper Personal Protective Equipments use according to the work			

No 5	Boiler Maintenance	Yes	No	Don't know
(i)	Have Regular Maintenance schedule			
(ii)	Maintenance is done by a trained Mechanic			

APPENDIX D

QUESTIONNAIRE DATA SHEET

Identify Economic Activity and type of Incident

** Details in this coloumn was deleted to prevent identifying organizations

D/coconut -Desicated Coconut Food & BV - food and beverages

	Organization Name **	Economic Activity	Type of Incident reported									
			Boiler Explosion	Fire	Steam Leakage	Fuel Leakage	Exposure to Chemical/Chemical Leakage	Burn Injuries to workers	Electrocution /Electric shock	Slips and falls at boiler Room	Exposure to higher Noise / vibration/Radc	other
1		Tea	X									
2		Rice	X									
3		Rice		X								
4		Rice	X									
5		Rice	X									
6		Rice	X									
7		Textile		X								
8		Tea	X									
9		Rice	X									
10		Rice	X									
11		Tea	X									
12		Rubber	X									
13		Rubber	X									
14		Sugar		X								
15		Tea	X									
16		Rice	X									
17		Rice	X									
18		Rice	X									
19		Rubber	X									
20		Rice	X									

QUESTIONNAIRE DATA SHEET

Identify Economic Activity and type of Incident

** Details in this coloumn was deleted to prevent identifying organizations

D/coconut -Desicated Coconut Food & BV - food and beverages

	Name **	Activity	Boiler Explosion	Fire	Steam Leakage	Fuel Leakage	Exposure to Chemical/Chemical Leakage	Burn Injuries to workers	Electrocution /Electric shock	Slips and falls at boiler Room	Exposure to higher Noise / vibration/Radon	other
21		Tea	X									
22		Rice	X									
23		Bakery			X							
24		Bakery			X							
25		Textile		X								
26		Tobacoo				X						
27		Food &BV			X							
28		Food &BV			X							
29		Rubber						X				
30		Textile			X							
31		Textile			X							
32		Textile			X							
33		Textile				X						
34		D/coconut			X							
35		Rubber				X						
36		D/coconut				X						
37		D/coconut				X						
38		D/coconut			X							
39		D/coconut			X							
40		Textile		X								

QUESTIONNAIRE DATA SHEET

Identify Economic Activity and type of Incident

** Details in this coloumn was deleted to prevent identifying organizations

D/coconut -Desicated Coconut Food & BV - food and beverages

	Organization Name **	Economic Activity	Type of Incident reported									
			Boiler Explosion	Fire	Steam Leakage	Fuel Leakage	Exposure to Chemical/Chemical Leakage	Burn Injuries to workers	Electrocution /Electric shock	Slips and falls at boiler Room	Exposure to higher Noise / vibration/Radon	other
41		D/coconut		X								
42		Rubber	X									
43		Rice		X								
44		Rice			X							
45		Rice			X							
46		Rice		X								
47		Rice				X						
48		Rice		X								
49		Rice	X									
50		Food & BV				X						
51		Textile			X							
52		Textile				X						
53		D/ coconut			X							
54		Rubber				X						
55		D/ coconut				X						
56		D/ coconut				X						
57		D/ coconut			X							
58		D/ coconut			X							
59		Textile		X								
60		D/ coconut		X								

APPENDIX E

QUESTIONNAIRE DATA SHEET

Identify Reason/Reasons for Incident

Rank : Not at all-1 Fair-2 Moderate-3 high-4 Critical-5

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Respondent	Faulty design	Defects of Materials	Fabrication Error	Improper Installation	Low water condition	Safety valve not working	pressure Gague not working	Operator errors	operate without boiler attending certificate	Failure to inspect during regular periods	Poor maintenance	Unsafe modifications	Exposure to Higher Noise level	Prolonged work at high temperatuers	Vibration of Boiler Parts	Use chemicals without PPE	Exposure to fly Ash	Work at height	Fuel leakage	Steam leakage
1	1	1	1	1	5	2	2	4	1	1	3	1	1	1	1	1	1	1	1	1
2	1	1	1	1	5	2	2	2	3	3	4	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	2	2	2	4	4	5	1	1	1	1	1	1	1	1	1
4	4	1	5	1	1	3	3	2	2	2	5	1	1	1	1	1	1	1	1	1
5	3	5	5	1	1	2	2	4	3	3	3	2	1	1	1	1	1	1	1	1
6	3	2	5	5	1	2	2	2	4	4	5	5	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	2	1	1	4	1	1	1	1	1	1	1	1	1
8	1	3	5	1	4	1	1	1	3	4	1	1	1	1	1	1	1	1	1	1
9	2	2	2	1	3	1	1	1	2	2	5	1	1	1	1	1	1	1	1	1
10	1	1	1	1	2	1	1	2	3	4	5	1	1	1	1	1	1	1	1	1
11	1	1	1	1	5	1	1	4	3	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	5	1	1	1	1	1	1	1	1	1	1	1	1
13	1	1	5	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1
14	1	1	5	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1
15	1	1	1	1	5	1	1	3	3	1	2	1	1	1	1	1	1	1	1	1
16	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
17	1	1	1	1	5	1	1	4	3	1	2	1	1	1	1	1	1	1	1	1
18	1	1	1	1	3	1	1	2	2	2	4	1	1	1	1	1	1	1	1	1
19	1	1	1	1	1	1	1	2	2	3	5	1	1	1	1	1	1	1	1	1
20	1	1	1	1	1	1	1	1	1	1	5	1	1	1	1	1	1	1	1	1
21	1	1	5	1	2	1	1	2	2	2	1	1	1	1	1	1	1	1	1	1
22	1	1	1	1	5	1	1	4	3	1	1	1	1	1	1	1	1	1	1	1
23	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	5
24	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	5
25	1	1	1	1	1	1	1	1	2	1	4	1	1	1	1	1	1	1	1	1

QUESTIONNAIRE DATA SHEET(Cont.)

Identify Reason/Reasons for Incident

Rank : Not at all-1 Fair-2 Moderate-3 high-4 Critical-5

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Respondent	Faulty design	Defects of Materials	Fabrication Error	Improper Installation	Low water condition	Safety valve not working	pressure Gague not working	Operator errors	operate without boiler attending certificate	Failure to inspect during regular periods	Poor maintenance	Unsafe modifications	Exposure to Higher Noise level	Prolonged work at high temperatuers	Vibration of Boiler Parts	Use chemicals without PPE	Exposure to fly Ash	Work at height	Fuel leakage	Steam leakage
26	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	5	1
27	1	1	1	1	1	1	1	3	1	1	3	1	1	1	1	1	1	1	1	5
28	1	1	1	1	1	1	1	2	1	1	3	1	1	1	1	1	1	1	1	5
29	1	1	1	1	1	1	1	5	1	1	1	1	1	1	1	1	1	1	1	1
30	1	1	1	1	1	1	1	3	1	1	4	1	1	1	1	1	1	1	1	1
31	1	1	1	1	1	1	1	2	1	1	3	1	1	1	1	1	1	1	1	5
32	1	1	1	1	1	1	1	2	1	1	3	1	1	1	1	1	1	1	1	5
33	1	1	1	1	1	1	1	2	1	1	2	1	1	1	1	1	1	1	5	1
34	1	1	1	1	1	1	1	2	1	1	2	1	1	1	1	1	1	1	1	5
35	1	1	1	1	1	1	1	2	1	1	2	1	1	1	1	1	1	1	5	1
36	1	1	1	1	1	1	1	2	1	1	3	1	1	1	1	1	1	1	5	1
37	1	1	1	1	1	1	1	2	1	1	3	1	1	1	1	1	1	1	5	1
38	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	5
39	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	5
40	1	1	1	1	1	1	1	3	1	1	4	1	1	1	1	1	1	1	1	1
41	1	1	1	1	1	1	1	2	1	1	4	1	1	1	1	1	1	1	1	1
42	5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
43	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1
44	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	5
45	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	5
46	1	1	1	1	1	1	1	3	1	1	5	1	1	1	1	1	1	1	1	1
47	1	1	1	1	1	1	1	3	1	1	2	1	1	1	1	1	1	1	5	1
48	1	1	1	1	1	1	1	2	2	2	3	1	1	1	1	1	1	1	1	5
49	1	1	4	1	1	1	1	1	2	2	1	1	1	1	1	1	1	1	1	1
50	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	5	1

QUESTIONNAIRE DATA SHEET(Cont.)

Identify Reason/Reasons for Incident

Rank : Not at all-1 Fair-2 Moderate-3 high-4 Critical-5

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Respondent	Faulty design	Defects of Materials	Fabrication Error	Improper Installation	Low water condition	Safety valve not working	pressure Gague not working	Operator errors	operate without boiler attending certificate	Failure to inspect during regular periods	Poor maintenance	Unsafe modifications	Exposure to Higher Noise level	Prolonged work at high temperatuers	Vibration of Boiler Parts	Use chemicals without PPE	Exposure to fly Ash	Work at height	Fuel leakage	Steam leakage
51	1	1	1	1	1	1	1	2	1	1	2	1	1	1	1	1	1	1	5	1
52	1	1	1	1	1	1	1	2	1	1	3	1	1	1	1	1	1	1	5	1
53	1	1	1	1	1	1	1	2	1	1	3	1	1	1	1	1	1	1	5	1
54	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	5
55	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	5
56	1	1	1	1	1	1	1	3	1	1	4	1	1	1	1	1	1	1	1	1
57	1	1	1	1	1	1	1	2	1	1	4	1	1	1	1	1	1	1	1	1
58	5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
59	1	1	1	1	1	1	1	1	1	1	5	1	1	1	1	1	1	1	1	1
60	1	1	5	1	2	1	1	2	2	2	1	1	1	1	1	1	1	1	1	1

APPENDIX F
SUMMARY OF QUESTIONNAIRE DATA SHEET

Identify level of work practices in Steam Boiler incident reported factories.

Steam Boiler Manufacturing	**Yes**	**No**	**Don't No**
Use a locally Manufactured Boiler	27	33	0
Manufactuers guide lines & Instructions at the factory	15	38	7
Install in a separate boiler House	38	22	0
Safety & Monitoring devices are available	50	10	0
Boiler structural defects tested within last one year	7	32	21

Steam Boiler Operation	**Yes**	**No**	**Don't No**
Pressure and water level check while operating	25	35	0
Boiler /operation instructions displayed closed to the boiler	13	47	0
Fire Safety Equipments available at the boiler house	15	45	0
Proper Personal Protective equipments use	9	51	0

Steam Boiler Operator	**Yes**	**No**	**Don't No**
Separate operator for boiler operation	25	35	0
Obtained Boiler attending certificate	29	31	0
Received outside training about boiler	13	41	6

Steam Boiler Inspection	**Yes**	**No**	**Don't No**
Inspected by an authorized boiler Inspector & obtain a certificate	44	16	0
Recommended Repairs done after authorized officer's inspection	17	20	23

Steam Boiler Maintenance	Yes	No	Don't No
Have Regular Maintenance schedule	11	48	1
Maintenance is done by a trained Mechanic	10	42	8

APPENDIX G
SUMMARY OF QUESTIONNAIRE DATA SHEET

Identify level of work practices in factories, Steam Boiler incidents not-reported

Steam Boiler Manufacturing	Yes	No	Don't No
Locally Manufactured Boiler	9	51	0
Manufacture's guide lines & Instructions at the factory	14	44	2
Install in a separate boiler House	47	13	0
Safety & Monitoring devices are available	60	0	0
Boiler structural defects tested within last one year	8	34	18

Steam Boiler Operation	Yes	No	Don't No
Pressure and water level check while operating	40	3	17
Boiler /operation instructions displayed closed to the boiler	20	35	5
Fire Safety Equipments available at the boiler house	33	27	0
Proper Personal Protective available at the boiler house	13	44	3

Steam Boiler Operator	Yes	No	Don't No
Separate operator for boiler operation	47	13	0
Obtained Boiler attending certificate	48	8	4
Received outside training about boiler	21	23	16

Steam Boiler Inspection	Yes	No	Don't No
Inspected by an authorized boiler Inspector & obtain a certificate	42	16	2
Recommended Repairs done after authorized officer s inspection	32	9	19

SUMMARY OF QUESTIONNAIRE DATA SHEET

Identify level of work practices in factories, Steam Boiler incidents not-reported (cont.)

Steam Boiler Maintenance	Yes	No	Don't No
Have Regular Maintenance schedule	25	31	4
Maintenance is done by a trained Mechanic	32	23	5

APPENDIX H

EXPERT INTERVIEW DETAILS

Questions on steam boiler hazards, steam boiler failures, SB operation and steam boiler manufacturing

Steam Boiler Hazards and Failures

01. In your opinion what are the possible steam boiler related hazards.?

02. What are the possible reasons for boiler failures…?

03. Do you think unsafe actions and unsafe conditions lead for boiler failures.?

04. What those unsafe actions and unsafe conditions lead for boiler failures.?

05. Are those failures generate SB related hazards.?

Steam boiler operation

01. Do you think SB registration is required to maintain boiler safety?

02. In your opinion what are the benefits of SB registration?

03. Do you think powerful legal frame work is required to maintain boiler safety?

04. What are your suggestions to strength the existing law enforcement?

05. Do you think that lack of safety awareness lead for boiler accidents and other hazards?

06. What type of activities you propose to improve employer and employee OSH knowledge on steam boiler?

07. Do you think boiler operator knowledge and behavior have effect on boiler safety?

08. "Boiler attending certification is a method used to appoint qualified boiler operators in Sri Lanka" What type of actions needs to improve this certification process?

09. What do you propose to do, enhance technical and safety knowledge of current and future boiler attending staff?

10. "Periodic Boiler Inspection is helped to identify structural and functional defects of a steam boiler" Do you agree with this statement?

11. In your opinion what are the reasons lead for not conducting periodic SB inspections?

12. What do you propose to improve boiler inspector's performance?

13. In your opining which type of in-house facilities need to maintain / develop for hazard control?

Boiler Manufacturing

1. "Registration of SB manufacturers is important factor to enhance quality of SB" Do you agree with this statement...?

2. Do you think "steam boiler standards" have an effect on quality of a boiler...?

3. As your opinion how these standards help to manufacture a safe and quality Steam Boiler...?

4. Which activities you propose to provide technical support to local manufacturers...?

5. As your opinion what type of actions need to ensure safety of imported Steam boilers...?

6. “It is necessary to inspect SB manufacturing Process by an authorized inspector”. Do you agree with this opinion...?

7. How these inspections help to improve Steam boiler manufacturing...?

8. Do you think existing rules and regulations enough to maintain proper manufacturing...?

9. What are your suggestions to improve existing legal frame work…?

10. Do you have any other suggestions to improve Steam Boiler manufacturing process…?