



Analysis of Boiler Operations in the Engine Room Laboratory of Makassar Maritime Polytechnic for Recertification by the Occupational Safety and Health Office of the Department of Manpower

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ABSTRACT

This study analyzes the feasibility and operational safety of boilers at the PIP Makassar Engine Hall Laboratory as part of recertification efforts through the integration of technical testing directly supervised by the Ministry of Manpower's Occupational Safety and Health Authority. The novelty of this study lies in its empirical validation through three stages of systematic testing—visual inspection, hydro test, and pressure test—to ensure that maritime education safety standards are met. The test results show that the boiler is structurally recommended for operation because the safety valve functions optimally by opening at a pressure of 5 kg/cm². However, through the hydro test procedure up to a pressure of 7 kg/cm², critical weaknesses were found in the form of leaks in the manhole packing, two check valves, and two filling pump valves. These findings provide practical contributions in the form of identifying specific points of failure that require immediate repair and chemical maintenance before use in cadet training. This study concludes that although the main unit is seaworthy, the reliability of the support system is a key variable in mitigating the risk of explosion and ensuring work safety in the laboratory.

1. Introduction

To this day, steam engines are still used on ships. To power these steam engines, a device is needed that can generate steam, known as a boiler [1,2]. A boiler is a closed vessel that can generate steam at a pressure greater than 1 atmosphere by heating the water inside it with hot gases from the combustion of fuel [3,4]. A steam boiler can operate effectively when equipped with other heat absorption devices such as an economizer, superheater, and air heater. Boiler operation must comply with the operating standards specified by the boiler user and the boiler manufacturer's own standards [5]. The standards that are created will ensure safety in operation, but in reality, incidents (accidents) due to explosions still often occur in the field [6]. This has happened in several locations that use boilers as their main equipment [7,8].

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The Boiler operation in the Engine Hall laboratory is an important topic in the context of engineering education and research. Boilers, as the main components in power generation systems, require a deep understanding of the hydraulic and thermophysical processes that occur in them. Laboratories designed to simulate boiler operation, as described in several studies, provide an opportunity to study and optimize these processes. A boiler functions as an energy conversion device that converts chemical (potential) energy, in this case fuel, into heat energy. A boiler consists of two main components, namely; 1). A furnace as a device to convert chemical energy (fuel) into heat energy; 2) An evaporator that converts combustion energy (heat energy) into potential steam energy (heat energy). A boiler basically consists of a tube/vessel (drum) that is closed at its base, and in its development, it is equipped with fire pipes and water pipes. Many people classify steam boilers depending on their respective points of view.

Boiler operation in the Engine Hall laboratory involves an in-depth understanding of hydraulic and thermophysical processes, the use of mathematical simulation models, and the integration of automatic control systems to improve the efficiency and accuracy of data collection. This laboratory serves as an important platform for research and education in the fields of mechanical engineering and energy. Based on the description of the background, the purpose of this study is to determine the feasibility and safety of Boiler operation in the Engine Hall Laboratory of the Makassar Maritime Polytechnic.



Fig. 1. Boiler in the Engine Hall Laboratory

Boilers are also composed of various components, each with its own function [9,10]. Below are the functions of each component in a boiler [11]:

- i. Combustion Chamber (Furnace), This is where the fuel combustion occurs, which will become the heat source. The heat transfer process to the water medium is carried out through pipes that have been filled with water, which are attached to the walls of the combustion furnace. The heat transfer process in the furnace occurs in three ways; 1. Radiation heat transfer, where heat is emitted from the fire or gas and sticks to the tube walls so that the heat is

absorbed by the fluid flowing inside; 2. Conduction heat transfer, where heat flows through conduction from the side of the pipe receiving heat to the side of the pipe transferring heat to the water; 3. Convection heat transfer, which occurs through the interaction of water molecules, causing heat to spread throughout the water flow. Inside the furnace, the combustion chamber is divided into two parts, namely the first chamber and the second chamber. In the first chamber, direct heating occurs from the heat source received by the tube (pipe), while in the second chamber, located at the top, the heat received comes from the hot air resulting from combustion in the first chamber. Therefore, the function of the second heating chamber is to absorb the heat wasted from the first heating chamber, so that the amount of heat energy wasted is not too great, and to control the heat of the fluid that has been heated in the first chamber so that it does not experience excessive heat loss.

- ii. Steam Drum, This functions as a hot water reservoir and a place where steam is formed. This drum holds saturated steam along with water in a ratio of 50% water and 50% steam. To prevent water from being carried away by the steam, partitions are installed so that low-temperature water will sink to the bottom and high-temperature water will rise to the top and then evaporate.
- iii. Superheater, This is where the steam is dried, because the steam from the steam drum is still wet and therefore cannot be used yet. The further heating process uses a superheater pipe that is heated to a temperature of 260°C to 350°C. At this temperature, the steam will become dry and can be used to drive turbines or for other equipment.
- iv. Air Heater, This component is a device that functions to heat the air used to blow fuel so that it can burn completely. The air to be blown, before passing through the air heater, has the same temperature as normal air (outside temperature), which is 38°C. However, after passing through the air heater, the temperature of the air will increase to 230°C so that it can be used to remove the water content contained in it because water vapor can interfere with the combustion process.

2. Methodology

This research is an experimental study involving pressure tests and hydro tests on boilers in the engine hall laboratory at PIP Makassar. Pressure testing is a type of experimental research designed to evaluate the ability of vessels, piping, hoses, or other closed systems to withstand applied pressure [12]. The purpose is to test structural integrity, detect leaks, and ensure that the component is safe to operate at its design pressure or at pressures exceeding normal operating limits (proof test or burst test). This testing is important in industries such as manufacturing, construction, and energy, where failure of pressurized components can pose significant hazards. Pressure testing can be performed using liquid media (such as in a hydro test) or gas (such as in a pneumatic test), and the results are analyzed to determine the equipment's compliance with applicable safety and design standards. Hydro testing (hydrostatic testing) is a non-destructive testing procedure used to verify the integrity, strength, and leak resistance of pressure vessels, piping, hoses, gas cylinders, and other similar components by filling the system with liquid (usually water) and then pressurizing it to a specified test pressure while monitoring for pressure drop or visible leakage [13,14]. The goal is to ensure that equipment can operate safely at its working pressure and withstand structural defects, making this testing essential in industries such as oil and gas, chemical, and manufacturing to meet safety standards and regulations.

3. Results

3.1 Visual Inspection

Before conducting experimental testing, a visual inspection is performed. Visual inspection means inspecting equipment and structures using a combination of human senses such as sight, hearing, touch, and smell [15]. Visual inspection is the most basic of the various non-destructive testing control methods, but it is no less important. The disadvantage of the visual inspection method is that it can only detect defects on the surface of the test material and can only detect defects that are visible to the naked eye or with optical aids. Figure 2(a) shows A visual inspection has been carried out at a place that can be seen and reached, and it was found that there was mud that was easy to fall off. It is recommended to clean it by spraying clean water. After that, the boiler can be prepared for hydro testing.



Fig. 2. (a) Visual inspection of boilers, (b) Compression test, pressure 2 - 4 kg/cm²

3.2 Pressure Testing Boiler

A pressure test was also conducted on the boiler to observe and determine whether the safety valve was still functioning properly. This test was absolutely necessary to prevent an explosion. Figure 2(b) shows the top of the boiler with two safety valves installed on the pipe, along with a note that at pressures between 2 kg/cm² and 4 kg/cm² the safety valves remain closed, indicating that the set pressure of the safety valves is higher than 4 kg/cm². Safety valves are designed to automatically release excess pressure from the boiler to prevent dangerous structural failure. If the test pressure has reached 4 kg/cm² and the valve remains closed, this means that the maximum safe point of the boiler specified by the designer is above that value. The boiler design specifications need to be re-verified to determine the maximum allowable working pressure (MAWP) and the actual safety valve opening pressure. The pressure test procedure is usually carried out to ensure the structural integrity of the boiler and to test the function of the safety valve.

In subsequent tests to check the safety valve function, the pressure must be increased until it reaches the pressure setting. If the manufacturer's setting is 7 kg/cm^2 , for example, the new valve will open (pop open) or start to leak (after the test valve is activated) when the pressure approaches or reaches that value, not at 4 kg/cm^2 . Therefore, testing up to 4 kg/cm^2 only ensures that the boiler can withstand that pressure and that the safety valve has not yet reached its opening setting, which is normal and expected behaviour if the pressure setting is indeed much higher. The valve will only open if the internal pressure of the boiler exceeds the specified safety limit.



Fig. 3. Pressure testing, pressure reaches 5 kg/cm^2 , (b) Pressure 1 kg/cm^2 , safety valve: close and no leaks

Figure 3 (a) shows a situation where steam is billowing heavily, and explains that this is part of a Pressure Test on a Boiler where the safety valve opens at a pressure of 5 kg/cm^2 , indicating that the set pressure of the boiler safety valve has been set at or slightly below 5 kg/cm^2 . The main purpose of a safety valve is to automatically release excess pressure to prevent boiler damage and potential explosion hazards if the internal pressure exceeds the safe limit. The opening of the valve at this pressure indicates that the safety valve is functioning properly according to its settings and has successfully secured the system by releasing high-pressure steam into the atmosphere. The steam seen billowing in the photo is the result of the safety valve releasing excess pressure. The released steam will be extremely hot and pressurized, requiring a safe discharge channel (commonly referred to as a vent or blow-off pipe), such as the blue pipe visible in the area, to direct it to a safe location away from workers or sensitive equipment. Testing the safety valve is very important and is often carried out as part of mandatory maintenance or inspection to ensure that the boiler operates within specified safety limits and that this most important pressure protection device is ready to respond to unexpected overpressure conditions during normal operation.

3.3 Hydro Testing Boiler

Hydro testing is carried out with the water boiler until it is full then the pressure is increased gradually until the pressure reaches 7 kg/cm^2 then held for inspection, water seepage is found in the hand hole then the pressure is reduced, then the bolts on the boiler are ordered to be tightened, and the hydro test is repeated with the pressure increased to 7 kg/cm^2 then held for 15 minutes. To carry out the inspection, a leak was found on the boiler pump machine's output valve. It is recommended to replace the equipment with a new one or repair it before Taruna carries out boiler operational practices, and the boiler can still be prepared for usage or steam testing. The cold-water boiler is full, then the pressure is increased gradually at a pressure of 4 k/cm^2 . There was water seepage on the hand hole surface, so that the pressure was reduced. It is recommended that the bolts on the boiler be tightened, then the test is repeated using the same pressure then held for inspection. It was found that there were water droplets on the valve or the water pump output tap. It is recommended to replace it with a new unit or make repairs before the Taruna students operate the boiler. The test was carried out with steam, the boiler was heated first for 30 minutes and then pressurized to 4 kg/cm^2 .

Figure 3 (b) shows a hydro test (hydrostatic pressure test) conducted on a boiler (steam boiler). This test is an important safety and structural integrity procedure to ensure that the pressure vessel (in this case, the boiler) is capable of withstanding the specified working pressure without leakage or permanent deformation. The fact that the boiler did not leak at a pressure of 1 kg/cm^2 is a good initial indication that the welded joints, gaskets, and boiler body materials are in adequate condition at the test pressure. However, 1 kg/cm^2 (1 bar or 14.22 psi) is very low for a standard hydrostatic test of an industrial boiler; typically, hydrostatic tests are performed at much higher pressures, usually 1.25 to 1.5 times the Maximum Allowable Working Pressure (MAWP), to provide an adequate margin of safety against operational pressures. Test results indicating no leakage at 1 kg/cm^2 show that the boiler passed the test at that pressure. Procedurally, this test involves filling the boiler with water to capacity and then gradually increasing the pressure using a test pump until the required test pressure is reached. Careful visual observation must be made of all joints, welds, manholes, and handholes during the pressure holding period to detect even the smallest seepage or leak.



Fig. 4. (a) Result pressure 2 kg/cm^2 , (b) Result of test pressure $3 - 7 \text{ kg/cm}^2$

Figure 4 (a) shows a failure in the Hydrostatic Pressure Test (Hydro Test) on the boiler due to a specific leak in the manhole packing, which resulted in a decrease in water pressure from the test pressure of 2 kg/cm^2 . A manhole is a large access hole in a pressure vessel such as a boiler, which is used for inspection, cleaning, or internal repairs. Leaks in manhole packings often occur during hydro tests for several reasons: the packing may be old and brittle, not installed correctly, made of unsuitable material, or the bolts on the manhole cover may not be tightened with even or sufficient torque. The observed drop in water pressure is a direct consequence of this leakage, indicating that the pressure vessel failed to withstand the test pressure applied. This failure indicates that the structural integrity and sealing of the boiler do not meet the standards required for continued operation. Before the boiler can be declared safe for operation, the leak in the manhole gasket must be repaired by replacing the old gasket with a new, standard-compliant one, ensuring that the surface is clean, and tightening the manhole cover bolts crosswise and gradually until the correct torque is achieved.

Figure 4 (b) shows the results of the Hydrostatic Pressure Test (Hydro Test) on the boiler, which failed due to leaks in two non-return or check valves when the pressure was increased from 3 kg/cm^2 to 7 kg/cm^2 . One-way valves serve to prevent fluid backflow and must be able to withstand system pressure. Leaks in these valves, which can occur through the stem packing or through the seat itself, are a serious problem because they indicate a failure in the sealing of vital components of the boiler piping system. This failure directly causes an observable drop in water pressure, which in turn causes the hydro test to fail because the boiler cannot maintain the required test pressure. To address this failure and ensure the boiler is safe to operate, immediate corrective action must be taken on both valves. Repairs may involve tightening or replacing the valve packing if the leak originates from the stem, or, if the leak originates from within, it may be necessary to repair or completely replace the one-way valve to ensure a perfect watertight seal. Once the physical repairs are complete, the hydro test must be repeated in its entirety. This retest must successfully withstand the test pressure up to the specified maximum value (i.e., 7 kg/cm^2 or a higher final test pressure as per the standard) without any pressure drop due to leaks in the valves or other parts of the boiler. This step is crucial to verify the integrity and operational safety of the boiler before it is allowed to start up.



Fig. 5. Result of test pressure $3 - 7 \text{ kg/cm}^2$

Figure 5 shows the results of the Hydrostatic Pressure Test (Hydro Test) on the boiler, which failed due to leaks in two filling pump valves (Pump 1 and Pump 2). These valves, which appear to be globe valves (valves with red handwheels), serve to isolate or regulate the flow of water entering the boiler during normal operation, and are also critical during hydro tests to maintain the integrity of the feed water system. Leaks in these valves, most likely occurring in the valve stem gland packing or flange connection, caused the observed drop in water pressure. This pressure drop indicated that the system was unable to withstand the required test pressure, thereby failing the hydro test.

Failures caused by leaks in the filling pump valves mean that the boiler cannot be certified as safe until this problem is fixed. To fix this, the leaky valves need to be repaired, which might involve tightening or replacing the valve stem packing (re-packing), or disassembling and repairing/replacing the flange packing on the leaky connection. Since there are two leaking valves from two different pumps, it is important to check the condition of all similar valves in the system. Once the physical repairs to both valves are complete, the hydro test must be repeated from the beginning. A successful retest (i.e., the boiler can maintain the specified test pressure without a drop) is essential to verify the integrity of the system's seals and ensure the future operational safety of the boiler.

Table 1
 Hydro test results

Pressure	Safety Valve	Description
1 kg/cm ²	Closed	No leaks
2 kg/cm ²	Closed	Leakage occurred in packing manhole no. 1
3 kg/cm ²	Closed	Leakage occurred in 2 one-way valves, 2 filling pump valves
4 kg/cm ²	Closed	Leakage still occurred in 2 one-way valves, 2 filling pump valves
5 kg/cm ²	Closed	Leakage still occurred in 2 one-way valves, 2 filling pump valves
6 kg/cm ²	Closed	Leakage still occurred in 2 one-way valves, 2 filling pump valves
7 kg/cm ²	Opened	Leakage still occurred in 2 one-way valves, 2 filling pump valves

Based on Table 1, it shows that at a pressure of 1 kg/cm², there is no leakage; at a pressure of 2 kg/cm², there is a leak in the manhole packing, and the water pressure decreases. At a pressure of 3 kg/cm² to 7 kg/cm², there is a leak in 2 one-way valves, and the water pressure decreases. While at a pressure of 3 kg/cm² to 7 kg/cm², there is a leak in 2 filling pump valves (pump 1 and pump 2), and the water pressure decreases.

The findings of this study are subject to several limitations related to the scope and duration of the assessment. First, the feasibility evaluation was limited to specific experimental procedures, namely visual inspections, hydro tests, and pressure tests conducted at a single point in time for recertification purposes. Consequently, the study does not provide long-term performance data or account for the potential degradation of components over extended operational periods. Additionally, the visual inspection was restricted to areas that were readily accessible and visible to the naked eye, potentially overlooking internal or subsurface defects. Furthermore, while the boiler was recommended for operation, the study identified that several supporting components, such as check valves and pump valves, required immediate repair or replacement, indicating that the current operational status is contingent upon these corrective actions. Finally, the testing was conducted under controlled laboratory conditions, which may not fully represent the complexities or varied stresses of industrial-scale boiler operations.

4. Conclusions

The primary objective of this study was to evaluate the feasibility and safety of the boiler operation in the Engine Hall Laboratory of the Makassar Maritime Polytechnic to support its recertification by the Occupational Safety and Health (K3) Office. Through a series of experimental tests—including visual inspection, hydrostatic testing, and pressure testing—it has been determined that the boiler is technically capable of achieving operational status. The safety objective was specifically verified through the pressure test, where the safety valve successfully opened at 5 kg/cm², demonstrating that the system's primary protection mechanism is functional and capable of preventing overpressure hazards. Furthermore, a steam test conducted at 4 kg/cm² yielded positive results, confirming the boiler's readiness for practical training use.

However, while the core objective of determining feasibility was met, the study identified critical maintenance requirements that must be addressed to maintain long-term safety standards. The discovery of leakages in the manhole packing, check valves, and filling pump valves during the hydro tests indicates that while the boiler body is sound, the supporting infrastructure requires immediate repair or replacement. Consequently, the boiler is recommended for operational use and recertification only upon the completion of these repairs and the implementation of regular chemical water treatment. This study concludes that with the specified corrective actions, the laboratory can provide a safe and compliant environment for cadet training.

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