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Assessment and Optimization of Boiler Energy Efficiency at Universiti Tun Hussein Onn Malaysia

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Abstract

This technical report presents a comprehensive energy audit of the boiler systems at Universiti Tun Hussein Onn Malaysia, evaluating its boiler efficiency and identifying energy conservation measures by using sophisticated instrumentation such as the ST9450 thermal imaging camera, Fluke 59 Max infrared thermometer, and Meatrol ME435 Multi-Functional Power Quality Analyzer Data Logger Power Meter. This audit collected precise data on power consumption, surface temperatures, and heat leakages. This audit involved a detailed walk-through of the boiler plant room and steam supply system, followed by rigorous measurements and data analysis. Key parameters measured included flue gas temperature and steam supply pressures. Thermal imaging revealed significant heat leakages, suggesting areas for improved insulation. The data highlighted inefficiencies and potential energy savings. The findings contribute to lowering operational costs, reducing the university's environmental footprint, and enhancing educational opportunities for students.

1. Introduction

Boilers are integral in industries and educational institutions, serving purposes like steam generation and heating. They operate by combusting fuels to produce heat, which is then transferred to water or steam for various applications [1]. The efficiency of these systems directly impacts operational costs, environmental sustainability, and regulatory compliance [2]. Enhancing boiler efficiency has become a priority due to rising energy costs and global emphasis on reducing greenhouse gas emissions.

Universiti Tun Hussein Onn Malaysia (UTHM) employs boilers for educational purposes, providing students with hands-on experience in energy systems. However, the absence of a comprehensive energy audit since their installation raises concerns about potential inefficiencies and energy losses, leading to higher operational costs and environmental impact.

The literature underscores energy audits' critical role in identifying boiler system inefficiencies. Energy audits involve systematically assessing factors like combustion efficiency, heat transfer, insulation integrity, and emissions control [3]. [4] emphasized that modern boilers can achieve efficiencies exceeding 90% but often fail due to improper operation and maintenance. Common losses included flue gas losses, casing losses, and steam leakages [5]. Effective measures such as improving insulation, optimizing combustion systems, and utilizing economizers can significantly enhance boiler performance [6].

In addition, the adoption of detailed energy audits, which involve rigorous measurements and analysis, is recommended for comprehensive insights into energy performance and conservation opportunities [7]. The findings from such audits contribute not only to operational cost savings but also to achieving sustainability goals.

Objectives of this study include conducting a detailed energy audit of UTHM's boiler system, evaluating boiler efficiency and identifying key inefficiencies, utilizing thermal imaging to detect heat leakages, and proposing energy-saving measures to enhance system performance.

2. Methodology

The audit utilized advanced tools, including the Meatrol ME435 Power Analyzer, ST9450 Thermal Imaging Camera, and Fluke 59 Max Infrared Thermometer. These instruments measured critical parameters such as flue gas temperature, power consumption, and surface temperatures. The methodology involved:

1. Conducting a walkthrough audit of the boiler plant room and steam supply system.
2. Measuring boiler efficiency using direct methods.
3. Identifying heat leakages through thermal imaging.
4. Analysing energy losses and proposing actionable energy conservation measures.

2.1 Meatrol ME435 Multi-Functional Power Quality Analyser Data Logger Power Meter

The Meatrol ME435 Multi-Functional Power Quality Analyzer Data Logger Power Meter was used to monitor and record the boiler's power consumption and electrical parameters. This gadget gave crucial insights into the system's energy usage trends, allowing us to discover inefficiencies and potential for energy reduction. Accurate data on power consumption, voltage, current, and harmonic distortion allowed for a thorough examination of the electrical performance and its impact on total boiler efficiency. Figure 1 depicts the data logger and its accessories.

(a) **(b)** **(c)**

Fig. 1 *(a) Meatrol ME435 Multi-Functional Power Quality Analyser Data Logger Power Meter; (b) Voltage Clamp Wires; (c) Rogowski Coil*

2.2 Thermal Imaging Camera

This gadget was essential in detecting heat leaks throughout the steam pipe system. By recording thermal images, the camera identified locations where insulation was insufficient, or heat was wasted, which is critical for boosting energy conservation and system performance. The thermal imaging camera provides a non-invasive and rapid inspection of the whole pipe system, including a visual representation of temperature variations. Figure 2 shows the thermal imaging camera used for this audit.

(a) **(b)**

Fig. 2 *(a) Thermal Imaging Camera Model ST9450 Top View; (b) Thermal Imaging Camera Model ST9450 Side View*

2.3 Infrared Thermometer (Model Fluke 59 Max)

An infrared thermometer (Model Fluke 59 Max), shown in Figure 3, was used to test surface temperatures at various locations throughout the boiler system and its components. The infrared thermometer is especially useful for taking exact temperature measurements in hard-to-reach regions, ensuring that all system components run at ideal temperatures. This information is critical for detecting overheating problems, potential device failures, and regions where further insulation may be required.

(a) **(b)**

Fig. 3 *(a) Infrared Thermometer (Model Fluke 59 Max) Top View; (b) Infrared Thermometer (Model Fluke 59 Max) Side View*

2.4 Boiler Efficiency

The boiler efficiency can be calculated by the formula:

$$Boiler\ efficiency, \eta = \frac{Heat\ output^{(1)}}{Heat\ input^{(2)}} \times 100 \tag{1}$$

Where:
Heat output$^{(1)}$ [kJ] = Mass of steam produced [kg] x (Specific enthalpy of steam - Specific enthalpy of feed water) [kJ/kg]
Heat input$^{(2)}$ [kJ] = Quantity of fuel used [kg] x Net calorific value of fuel [kJ/kg]

Hence, the formula becomes [8]:

$$Boiler\ efficiency, \eta = \frac{(m_{fw} - m_b) \cdot (h_w + 0.98 \cdot \Delta H - h_{fw})}{m_{fl} \cdot H_f} \tag{2}$$

Where:
η: Boiler Efficiency (%)
m_{fw}: Feed water rate (kg/h)

m_b: Boiler blow-down rate (kg/h)
h_w: Specific enthalpy of saturated water (kJ/kg)
ΔH: Latent heat of steam (kJ/kg)
h_{fw}: Specific enthalpy of feed water (kJ/kg)
m_{fl}: Fuel consumption (kg/h)
H_f: Calorific value of fuel (kJ/kg)

Table 1 shows the recommended boiler efficiency based on their fuel type.

Table 1 *Recommended Boiler Efficiency* [13]

Type of Fuel	Full Load Efficiency (%)	Low Load Efficiency (%)
Coal	85	75
Oil	80	72
Gas	75	70
Biomass	70	60

3. Result and Discussion

This energy audit was conducted on the boiler systems at Universiti Tun Hussein Onn Malaysia (UTHM) to evaluate efficiency and propose energy-saving strategies. Thermal imaging identified heat losses and areas needing improved insulation. The findings offer practical recommendations to enhance boiler performance, lower costs, and support the university's sustainability goals.

3.1 Boiler Efficiency

3.1.1 Data Measured

Table 2 shows the data collected to perform the calculation for boiler efficiency.

Table 2 *Data Measured for Boiler*

Parameter	Value
Boiler pressure [psi]	100
Fuel Calorific Value [MJ/ kg]	43.5
Steam Temperature [°C]	153
Feed Water Temperature [°C]	30
$\dot{m}_{feedwater}$ [kg/h]	750
$\dot{m}_{diesel}$ [kg/h]	177.055
ρ_{water} [kg/m^3]	1000
ρ_{diesel}. [kg/m^3]	850

3.1.2 Calculation

$$Boiler\ efficiency, \eta = \frac{(m_{fw} - m_b) \cdot (h_w + 0.98 \cdot \Delta H - h_{fw})}{m_{fl} \cdot H_f} \tag{3}$$

$$= \frac{\left(750\,\frac{kg}{h} - 0\right) \cdot \left(694.2805\,\frac{kJ}{kg} + \left(0.98 \cdot 2067.62\,\frac{kJ}{kg}\right) - 125.74\,\frac{kJ}{kg}\right)}{\left(177.055\,\frac{kg}{h}\right)\left(43500\,\frac{kJ}{kg}\right)} \tag{4}$$

$$= 0.2527 \text{ @ } 25.27\% \tag{5}$$

Where:
η: Boiler Efficiency (%)
m_{fw}: Feed water rate (kg/h)
m_b: Boiler blow-down rate (kg/h)
h_w: Specific enthalpy of saturated water (kJ/kg) Table A-5 [14]
ΔH: Latent heat of steam (kJ/kg) Calculator: Saturated Steam Table by Pressure [15]
h_{fw}: Specific enthalpy of feed water (kJ/kg) Table A-4 [14]
m_{fl}: Fuel consumption (kg/h)
H_f: Calorific value of fuel (kJ/kg)

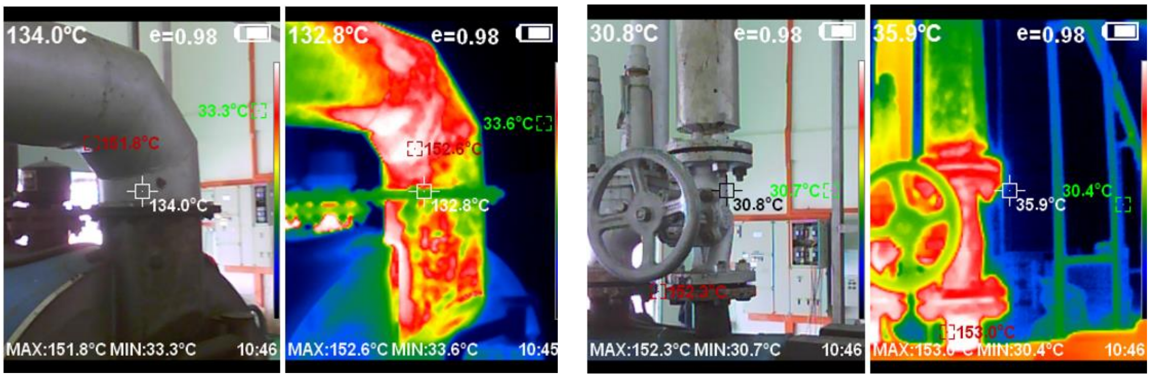
By inserting the measured values in Table 2, the boiler efficiency was 25.27%. As mentioned in Table 1 above, oil-type boilers should have an efficiency of about 80% at full load and 72% at low load. However, the boiler has a lower value than recommended, which is 25.27%. Therefore, a substantial overhaul or replacement of the high-efficiency boiler is recommended.

3.2 Energy Balance Analysis

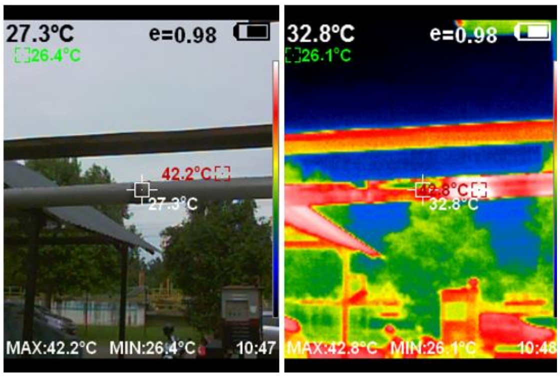
Energy balance analysis evaluates how effectively fuel energy is converted into usable energy in boilers while identifying various losses. Main losses include flue gas losses, where hot gases escape with unutilized energy due to high temperatures or incomplete combustion, mitigated by economizers and air-to-fuel ratio optimization [9]. Conduction and radiation losses occur through the boiler's heated surfaces, which can be minimized with proper insulation [6]. Unburned fuel losses arise from poor combustion, addressed through burner maintenance and high-quality fuel [10]. Steam leakage, caused by defective components, significantly reduces efficiency, as does incomplete combustion, where improper air-fuel mixing leaves unburned carbon [11]. Finally, blowdown losses occur due to the removal of water-containing impurities, which can be managed by optimizing the blowdown rate with automated systems [7], improving overall boiler efficiency, and reducing costs.

3.3 Thermal Imaging

Thermal imaging is used to detect steam leakage in the boiler system. The ST9450 thermal imaging camera is utilized to accomplish this task. Figure 4 depicts the thermal imaging for the boiler. It is worth noting that the boiler leaked steam. Thermal pictures of the steam supplied and returned are also presented. It is clarified that steam leakage was not identified in this audit. However, some photos show that the surface temperature at almost all sites is above 50°C. As an outcome, the insulation at these sites can be upgraded with modest repairs to reduce heat loss while ensuring worker safety, and well-being as recommended by the Energy Audit Guideline [16].



(a) (b)



(c)

Fig. 4 *(a) Boiler Exhaust Pipe; (b) Boiler Steam Outlet Pipe; (c) Steam Incoming to Heat Up Oil*

During the audit, the boiler operated at 100 psi based on the capacity of steam required for education purposes and for heating the oil in biodiesel when needed. As for the boiler system, it did not use anything to heat the water supply. The temperature of the water supply remains at ambient temperature, which is 30°C. Furthermore, the feed water tank is not insulated, which increases heat losses to the surroundings.

3.4 Observations and Findings

During the energy audit, it was observed that the boiler operated at a pressure of 100 psi, aligning with the steam capacity requirements for educational purposes. However, the boiler system lacked a preheating mechanism for the feedwater, with the water supply entering the system at ambient temperature, approximately 30°C. Furthermore, the feedwater tank lacked a preheating mechanism, resulting in feedwater being delivered into the boiler at a much lower temperature. The lack of preheating increases the thermal load on the boiler, necessitating more energy to bring the water temperature to the required levels for steam generation. As a result, this leads to increased fuel consumption, lower energy efficiency, and higher operational expenses for the boiler system [13].

3.5 Energy Saving Measures

The energy audit identified three key Energy Conservation Measures (ECMs) to enhance boiler efficiency and reduce energy waste. ECM 1 involves a major overhaul or replacement of aging boilers, as their efficiency declines over time; replacing the audited boiler, which has an efficiency of 25.27%. [12] has mention with a modern one boiler efficiency could achieve up to 95% efficiency. ECM 2 focuses on improving the insulation system of boiler pipes to reduce heat loss, lower energy costs, and enhance workplace safety by preventing burns. ECM 3 recommends installing an economizer to recover waste heat from flue gases, preheat feedwater, and improve thermal efficiency. This measure reduces fuel consumption, operational costs, and carbon emissions, supporting sustainable energy management. Proper maintenance of insulation and economizers ensures long-term efficiency and cost savings.

4. Conclusion

The energy audit of the boiler systems at Universiti Tun Hussein Onn Malaysia (UTHM) successfully achieved its objectives, providing a comprehensive evaluation of efficiency and identifying opportunities for improvement. The audit revealed a significantly low boiler efficiency of 25.27%, far below the recommended standards, emphasizing the need for immediate enhancements. Thermal imaging identified areas of excessive heat loss, highlighting weaknesses in insulation. Based on the findings, three energy conservation measures were proposed, including replacing or overhauling the boiler, improving insulation, and installing an economizer to recover waste heat. These recommendations aim to optimize energy usage, reduce operational costs, and support the university's sustainability goals, ensuring a more efficient and environmentally friendly boiler system.

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