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Economizer Manufacturing Process Optimization in Boiler Efficiency Improvement: A Literature Review

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Abstract. Boilers are one of the important components in the industrial sector, with their thermal efficiency largely dependent on the ability to utilize the heat energy produced. Economizer is the main device used to improve boiler efficiency by utilizing residual heat from flue gases to heat feed water, thereby reducing fuel consumption and greenhouse gas emissions. This research aims to review the literature related to optimizing the economizer manufacturing process, including material selection, design, and production technology, in order to improve boiler thermal efficiency. The review shows that materials such as stainless steel and copper have a great contribution in improving thermal conductivity and corrosion resistance. In addition, new material innovations, such as ceramic and polymer composites, offer significant potential for improving economizer performance. On the other hand, manufacturing processes such as high-precision welding and strict quality control prove instrumental in ensuring the structural integrity of the economizer. By optimizing manufacturing processes, boiler efficiency can increase by up to 15%, while supporting sustainability by reducing greenhouse gas emissions. This research confirms that further development in economizer design, materials and manufacturing technologies is necessary to meet the needs of a sustainable industry. Thus, economizer is not only a solution for energy efficiency but also a strategic step in supporting a more environmentally friendly energy system.

Keywords: boiler; economizer; thermal efficiency; manufacturing process; greenhouse gas emissions

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1. Introduction

Energy demand in Indonesia continues to increase from year to year. According to data from the State Electricity Company (PLN), the level of electricity consumption in Indonesia during the 2008-2018 period showed a fairly rapid upward trend (1). In this context, steam power plants (PLTU) such as boilers become one of the important components in various industrial sectors, such as the chemical industry, and manufacturing, which functions to produce steam by heating water using heat energy from fuel to rotate turbines and generators to produce electricity (2). The thermal efficiency of a boiler is highly dependent on its ability to convert heat energy into steam that can be used for various purposes. However, over time, many boilers experience a decrease in efficiency due to heat loss through flue gas, which itself can be reused for the process of heating feed water. A heat exchanger or commonly called an Economizer is a heating device installed in the boiler flue gas duct that functions as a wasted heat taker for the feed water reheating process, thereby reducing the amount of fuel needed to heat the water (3). Thus, economizer helps to increase the thermal efficiency of the boiler, reduce energy consumption, and lower operational costs (4).

Although the discussion on economizer optimization and technology has grown rapidly in recent years, studies linking the economizer manufacturing process with boiler efficiency improvement are still limited. In the last five years, economizer-related literature is divided into several main study

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clusters, namely: first, the effect of economizer use on boiler efficiency (4,5,6); second, the impact of corrosion on economizer (7,8,9); third, economizer design analysis to improve thermal performance (10,11,12); and fourth, heat transfer analysis in economizer (13,14,15). Among these clusters, the most emerging studies are those addressing the use of economizer to improve boiler efficiency (16,17,18,19).

However, although many studies have discussed the role of economizer in improving boiler efficiency, research on the relationship between economizer manufacturing process and such efficiency is still very rare. An optimal manufacturing process needs to perform material selection, manufacturing design, as well as the production technology used (20). This can directly contribute to the performance and effectiveness of the economizer in improving boiler efficiency.

The main objective of this research is to conduct a literature review related to the optimization of economizer manufacturing processes in the context of improving boiler efficiency, such as design, materials, and production technology, which can affect economizer performance and overall boiler efficiency. A more efficient manufacturing process and the use of materials with better thermal properties can extend the life of the economizer and improve its performance. However, implementing these solutions requires a deep understanding of the interaction between design, manufacturing, and their effect on boiler efficiency.

The goal of this research is to provide new insights into how optimization of the economizer manufacturing process can have a direct impact on reducing energy consumption and improving boiler thermal efficiency. This research is expected to provide recommendations regarding the best material and design for the economizer, as well as a better understanding of how the economizer manufacturing process can be improved to achieve more optimal performance. Thus, this research is expected to contribute in developing more efficient and environmentally friendly boiler technology in the future.

2. Methodology

This research uses a literature review approach to identify key factors in economizer manufacturing process optimization to improve boiler efficiency. Data was collected from various sources such as scientific journals published in the last 10 years. Literature selection criteria included relevance to the topics of boiler efficiency, economizer, manufacturing process, as well as studies that reported quantitative results related to thermal efficiency or fuel consumption.

After data collection, the literature was analyzed to identify patterns, trends and key findings. This analysis covered four main aspects: material selection, design parameters, manufacturing technology, and the impact of corrosion on economizer performance. The results of the analysis were used to develop a conceptual model of economizer manufacturing process optimization that included recommendations for materials, design parameters, and high-precision manufacturing technologies to improve efficiency and reliability.

3. Manufacturing Process Optimization

3.1 Boiler

A boiler, or steam boiler, is a closed vessel-shaped device that functions to convert the chemical energy in fuel into heat energy used to convert water into steam (21). Boilers have extensive fuel adaptability and low cost pollution control, so they are widely used in power generation. Boilers can easily handle the combustion of low-quality coal (calorific value less than 4,000 kcal) (22). The heat generated from the combustion of coal fuel in the form of combustion gases flows around the tubes containing water (water-tube boiler). The water in these tubes then absorbs heat from the combustion gases, turning into steam with high pressure and temperature (23).

Steam boilers are mostly used for industrial needs including power generation, food industry, pharmaceuticals, fertilizers, refineries, and others (24). Through the heating process, the energy contained in coal is converted into heat energy in the boiler furnace. To utilize the remaining heat energy from the flue gas, an economizer is used as an auxiliary heating device to improve the efficiency of the system (25).

3.2 Economizer

Economizer as an additional component in the boiler system which is one of the heat exchange devices that utilizes heat energy from flue gases to heat the boiler feed water before entering the steam drum (26). Preheating of the boiler feed water is achieved through the utilization of heat from the flue gases, which significantly reduces the heat energy requirement in the boiler (27). This, in turn, reduces fuel usage, thereby increasing the overall efficiency of the power generation system (28).

Economizer plays a crucial role in improving boiler efficiency in a smart and effective way. By utilizing the heat from the flue gas, the economizer heats the feed water before it enters the boiler. This process not only reduces the heat energy requirement in the boiler, but also saves fuel usage significantly. As a result, the power generation system becomes more efficient and environmentally friendly, while reducing overall operational costs (29).

In addition to improving energy efficiency, economizers also extend boiler life by reducing thermal stress on internal components. This lowers the risk of damage and maintenance costs (30). The use of economizer helps to increase feed water temperature, reduce fuel consumption thereby reducing greenhouse gas emissions, support sustainability efforts and comply with environmental regulations (31). One of the efforts to improve boiler efficiency is to do sootblower which functions to clean dust or soot attached to tubes, superheater tubes, reheater tubes, economizer tubes, and airheaters so that heat transfer is maximized and produces more stable efficiency (32).

3.3 Influence of Economizer Manufacturing Process on Boiler Efficiency

Proper material selection for economizer manufacturing is essential to ensure its optimal thermal performance. Materials such as stainless steel are often used in economizer manufacturing because they have high thermal conductivity as well as good resistance to corrosion. Stainless steel, for example, is chosen for its resistance to chemical reactions that occur due to exposure to acidic flue gases (33). In addition, this material is also able to withstand high temperatures, which is highly required in economizer applications that function to recover heat from combustion flue gases (34). Besides stainless steel, copper material is proven to have a better heat transfer coefficient than aluminum alloys, making it a superior choice for improving the thermal performance of economizers (35). Seamless pipes are also widely used due to their good strength, corrosion resistance, and ability to transfer heat efficiently (36).

In addition to conventional materials, new material innovations are now being developed in economizer efficiency and durability enhancement to demonstrate the potential of using innovative composite materials and metal alloys in improving economizer performance and durability. These advancements focus on improving thermal performance, mechanical properties, and overall reliability, which are critical for energy systems. Correspondingly, composite materials designed for structural applications are also subjected to testing, such as impact tests and other mechanical property evaluations, to ensure they are capable of meeting the needs of increasingly complex and efficient energy systems (37). The Ig/SnBi58 ceramic composite developed through microencapsulation showed significant improvements in thermal conductivity (5.75 W/(m-K)), compressive strength (49.38 MPa), and heat storage density (399.1 MJ/m^3). These superior properties make the composite a promising composite for thermal energy storage applications in economizers. These composites have the potential to improve the efficiency and durability of thermal energy storage systems (38). Polymer composite materials, which usually consist of two or more materials with different properties, can provide a combination of advantages such as light weight, high thermal conductivity, thermal stability up to 400°C, and corrosion resistance, which makes them an attractive option for applications in power generation systems (39).

In addition to material selection, the manufacturing process and quality of the economizer has a great influence on its performance. Processes such as welding techniques, precision cutting, and material fabrication with strict quality control are essential to ensure structural integrity and good economizer performance. High-precision welding is essential to ensure that the joints between economizer components are robust and not easily damaged by extreme pressure or temperature, which can reduce the efficiency and durability of the device (40). In addition, the fabrication process with strict quality control also prevents manufacturing defects that could affect the long-term performance of the economizer (41).

3.4 Design Innovation in Economizer to Improve Efficiency

The economizer design plays a crucial role, as various parameters such as fin spacing, tube configuration and pitch ratio can significantly affect the heat transfer performance, with a fin spacing of 21 mm resulting in the best thermal performance, with a 4% increase in water temperature. In addition, the effect of gas radiation on heat transfer proved to be minor, contributing less than 3% of the total heat transfer (42). Previous research used the Taguchi method to quickly and efficiently identify the optimal economizer design, resulting in a configuration with a tube diameter of 0.0381 m, pitch ratio of 1.2, excess area of 1.2, and tube spacing of 30°. This configuration significantly improved the heat transfer efficiency, reinforcing the importance of proper design in improving economizer thermal performance (43).

In addition, the optimal parameters for maximum heat flow rate were found to be 4 mm fin thickness, 5 mm fin height, 16 mm inter-fin spacing, and 48 mm tube diameter. Meanwhile, the maximum heat transfer was achieved with a fin thickness of 5 mm, fin height of 7 mm, inter-fin spacing of 16 mm, and tube diameter of 50 mm with the maximum S/N ratio value of the overall heat transfer recorded at 86.4343. These findings emphasize the importance of precise geometric parameter settings to maximize the thermal efficiency of the economizer (44).

3.5 Effect of Corrosion on Economizer Performance

Corrosion is a major problem that affects the performance of the economizer by causing thinning of its walls, which can reduce efficiency and shorten the life of the equipment (36). When the pipe wall is thinned to a certain extent due to corrosion, the pipe cannot withstand the pressure inside the pipe, thus causing the pipe to rupture, corrosion in the economizer is caused by dew point flue gas containing SO_2, SO_3, and HCl, which forms acid and accelerates the thinning of the tube wall until it fails to withstand the internal pressure (45). Exhaust gases containing moist sulfur undergo oxidation, where sulfur dioxide (SO_2) turns into sulfur trioxide (SO_3) which then reacts with water vapor to form sulfuric acid vapor (H_2SO_4). When the metal surface temperature drops below the dew point of H_2SO_4, which ranges from 120 to 150°C, this vapor condenses into liquid sulfuric acid. This phenomenon triggers severe corrosion of the metal surface, especially in stressed areas, due to the accumulation of sulfur-rich corrosion products (46). His research suggests that the application of special coatings on the material surface of the economizer can significantly improve its corrosion resistance, thus extending the life of the appliance and maintaining its efficiency. In addition, periodic maintenance of the parts exposed to flue gas is also recommended in order to maintain optimal performance of the economizer (47).

3.6 Use of Economizer in Improving Boiler Efficiency

Economizer is one of the technologies designed to improve the thermal efficiency of boilers by utilizing the flue heat of combustion gases (48). This technology is able to increase efficiency up to 15% by lowering the flue gas temperature below the dew point, thus utilizing the latent heat of condensation of water vapor contained in the flue gas (49). Studies show that optimal economizer implementation can increase efficiency by 10.55% by cooling the flue gas from 123°C to 47°C, and save 23,500,000 Nm^3 of natural gas consumption per year, depending on economizer design, fuel type, and boiler operation (50). This not only cuts operational costs but also provides significant benefits in large industrial sectors such as power plants, chemical plants, and manufacturing facilities (51).

Moreover, the reduction in fuel consumption also contributes to the reduction of greenhouse gas emissions such as CO2, NOx, and SOx, which is in line with global sustainability targets as well as carbon reduction policies in the industrial sector. These energy savings also help companies achieve sustainability goals in a more resource-efficient and environmentally friendly way (52).

4. Conclusion

This research reveals the importance of optimizing the economizer manufacturing process in increasing boiler thermal efficiency, which is a vital component in various industrial sectors. Through an in-depth literature review, an understanding was obtained that the economizer not only functions as a heat exchanger, but also as a strategic solution to reduce energy consumption, reduce operational costs and reduce greenhouse gas emissions. With thermal efficiency that can increase by up to 15%, economizers are proving to be a key element in creating a more sustainable energy system. The main aspects that influence economizer performance include material selection, design and manufacturing process. Materials such as stainless steel and copper make a significant contribution to improving thermal conductivity and corrosion resistance. New material innovations, such as ceramic and polymer composites, present great potential in extending the life of economizers and increasing their efficiency, while providing environmentally friendly solutions for modern industry. The manufacturing process also plays an equally important role. Manufacturing technologies such as high-precision welding, precision cutting and strict quality control ensure that the economizers produced have optimal structural integrity. However, the threat of corrosion due to exposure to exhaust gas containing sulfur remains a big challenge. The application of special protective coatings and routine maintenance are crucial mitigation measures to maintain the long-term efficiency of the economizer. The results of this research confirm that optimization in economizer design, materials and manufacturing technology not only provides significant benefits to boiler efficiency, but also contributes directly to environmental sustainability. By reducing fossil fuel consumption and greenhouse gas emissions, the use of an optimized economizer supports the creation of a more resource-efficient and environmentally friendly energy system. Therefore, investment in further research and development related to economizer technology is very necessary to answer future energy challenges and meet the demands of an increasingly competitive industry.

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