# Energy Efficiency Improvement Strategies for Boilers: A Case Study in Pharmacy Industry

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**Abstract.** Energy resources are gradually scarce and expensive. Raised a gap between increasing demand and energy supply. Bridging gap of demand together with energy supply by increase energy supplies is a very costly decision. Moreover, in the industrial sector with the high cost of energy, the longer the competitiveness decreases. Energy costs in total production costs reduce the number of profits each year. The strategy to prevent these problems is by increasing the efficiency of industrial operations and equipment. Several stages of the efficiency process begin with identifying balance, energy-saving opportunities, and energy utilization. This stage is better known as an energy audit. The advanced stage of the energy audit helps identify potential energy conservation and encourages the industry to focus on efficiency and conservation and is supported by adequate financing. In the research strategy, the opportunity to save energy costs in oil boiler units is practical, sustainable and economically feasible. On the results of measurements and calculations obtained boiler efficiency of 53.67% where the factors that cause the low efficiency of this boiler are the high excess water by 17.32% and heat loss from dry exhaust gas by 42.03%. The solution is done by controlling excess air by regulating the air entering the combustion chamber. In this way, energy savings can be increased by 15%.

Keywords: **Energy; oil Boiler; Efficiency; Excess air; Heat loss.**

## 1 Introduction

Energy is an important factor in an industrial operation, transportation, production processes, and other needs. The biggest energies for fulfilling the production process is thermal energy [1]. Thermal energy has a large contribution to the operational costs. In a production process, energy becomes important so that the industry has a high level of dependence on energy needs for its operations. So conservation efforts are needed to achieve efficiency goals. Energy conservation is implied as smart and efficient use of energy to confirm that a particular amount of maximum energy activity, productive work and profitability is achieved [2]. Considering cases above, decided to focus on energy conservation. Using energy conservation, savings can be achieved from 10% to 30% of energy and costs through simple actions [3].

Fulfill of thermal needs of pharmaceutical industry, 2 boilers use 1 Ton/ hour and 1.5 Ton/ hour were used, with different operating times for each boiler. Boilers are closed vessels where the combustion heat is poured into water through hot water or steam is formed. The important components in the boiler are burners, combustion chambers, heat exchangers and control systems. The right composition in mixing between fuel and air in the combustion chamber will produce perfect combustion. The heat delivery is transferred to water through a heat exchanger. Hot water or steam at a certain pressure is afterward used for the production process. In the process of producing water from steam, heat loss or loss can occur, such as heat lost formed as excess air and high temperatures in exhaust gases. Disadvantage due to unburnt substance in chimney and ash, loss from blowdown and condensate. Convection loss, radiation and water evaporation formed due to H2 in fuel. To optimize boiler operation, important to identify the sources of waste or loss. The losses found in the steam production process are exhaust gases which can reach 10-30% of total losses, with temperatures ranging from 150-250oC [4]. Therefore, employ of exhaust gas is very important to improve boiler efficiency, thus obtaining energy savings. One way to get a higher boiler efficiency is to use an economizer to preheat feed water using waste heat in the exhaust gas [5].

This study aims to obtain the actual conditions of energy needs and use in a steam demand process. Inefficiencies in the production process and steam use occur in this process, so steps need to be taken to increase this efficiency. In this study, identification, evaluation, and analysis of the steam flow in a steam

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generator/ boiler are used for the production process. The use of electricity, water, and fuel is also measured and calculated to determine the actual conditions of the boiler unit.

## 2 Materials and Method

This research includes several stages, including preparation and retrieval of data. There are 2 types of data collection, secondary data and primary data obtained from the measurement results. The analysis data are performed, identification of potential savings, then determining energy-saving opportunities. The stages of the research process as following below :

**1. Getting of pertinent Data Plant**

Before starting work or conservation studies, energy use and process operation data that are important for this study are obtained from factory management. Some important information is needed including monthly energy consumption profiles, equipment list based on parts, individual equipment and overall plant production levels, individual process equipment specifications, energy consumption for the entire plant and process equipment, operating periods and hours of plant operations and annual equipment, also fuel, type, characteristics, and composition.

**2. Technique of Energy Audit**

Energy audits are conducted to evaluate the efficiency of the equipment process system and all processes that use energy. The energy auditor starts work on the utility meter, finding all the energy sources that enter the facility. After that, identify the energy flow for each fuel used, quantify the energy flow into separate functions, evaluate the efficiency of each of these functions and identify energy and cost savings opportunities. Types of energy audits are current audits, total system audits, boiler/steam generator generation, steam system audits, and specific energy consumption.

**3. Energy Losses Determination**

After identifying the parts of equipment that consume major energy as the focus of the study, a more detailed analysis of energy consumption and losses is carried out. To realize the energy balance, process parameters such as exhaust gas, vapor flow rate, and fuel composition, pressure, temperature, and other boiler characteristics must be measured [6].
The measurement parameters needed are:

**Table 1**. Measure Parameters

| No. | Measurement | Parameter |
|---|---|---|
| **1** | Fuel | water rate ($m^3$/h), temperature (°C), pressure (kg/cm) |
| **2** | Exhaust gas | water rate/ exhaust gas volume ($m^3$/h), temperature, exhaust gas composition (% CO,% $CO_2$,% $O_2$) |
| **3** | Feedwater boiler | water rate, total dissolved solid material (TDS), pressure (kg/cm) |
| **4** | Air combustion | ambient temperature (°C), air humidity (%) |
| **5** | Water blowdown | water rate, amount of dissolved solid material (TSD), temperature (°C). |
| **5** | Boiler wall | temperature (°C), surface area (m) |
| **6** | Steam | water rate ($m^3$/h), temperature, pressure. |

1. Data Collection
The stages of this research are divided into 2 stages are :
a) Secondary data collection in the form of boiler energy history data

b) Primary data collection by measuring boiler water requirements, boiler electricity, fuel amount, steam production amount and emission concentration amount.

2. Research Location
Research location was carried out in the pharmaceutical factory utility unit with the research object of a steam generator (boiler) with a capacity of 1.5 tons/ hour. Steam from boilers is needed for the production process, sanitation process, and start-up process (in small quantities) with a total of 2,034.23 Kg/Hour. With an average operational process of 843.03 kg/hour, the sanitation process is 1019.6 kg/ hour, and the start up process is 171.6 kg/ hour. The boiler fuel needed is an average of 11.13 L / hour.
3. Analysis Data
The data obtained were then analyzed using quantitative descriptive analysis and energy calculations. The equipment used in this study is Power Quality, ultrasonic flow meter, infrared thermometer, thermal imager, leak detector, thermo-hydgrometer, gas analyzer, and thermometer.

## 3 Results

**A. Energy Efficiency in Boilers**

a) Energy efficiency in Boilers
The efficiency of the boiler can be improved by reducing the heat carried with the exhaust gas, with adequate insulation, and by controlling the flow of blowdown (with or without heat recovery from blowdown).
Overall boiler efficiency can be determined in 2 ways:
1. Direct Methode
Which is known as the 'input-output' method because it only requires usable output (steam) and heat input (fuel) to evaluate efficiency. This result is obtained from the energy of the working fluid (water and steam) compared to the energy content of the boiler fuel. Efficiency is estimated using the equation below:
Boiler efficiency = Heat output/ Heat input
Or Boiler efficiency = [Q x (hg- hf)/ q x GCV] x 100
where:
Q = quantity of steam generated per hour (Kg/hr).

q= quantity of fuel used per hour (Kg/hr).
hg = Enthalpy of saturated steam in Kcal/Kg of steam.
hf= Enthalpy of feed water in Kcal/kg of water.

2. Indirect Methode

Efficiency is compiled by losses generated by comparing with the incoming heat. The main heat loss from the boiler is combustion of high temperatures and the need for water to produce steam, combustion of hydrogen (stack of boilers as steam), combustion of heat in waste, radiation from the surface of the boiler, not counted for measured losses. The number of losses and efficiency calculations are calculated using equations [7].

$$\text{Efficiency } (\% \text{ E}) = 100 - \Sigma \text{ Losses}$$

The first method, although it is direct but very difficult to apply. To determine the amount of heat absorbed by steam, parameters such as steam flow, steam quality, and vapor pressure are needed which must be known precisely and accurately. The equipment needed to be able to measure the prices above is very expensive and must always be maintained. Many factories that boilers are not equipped with this equipment.

The second method determines efficiency indirectly by determining the amount of all heat loss [8]. To improve boiler efficiency, the most logical way is to look for things that cause loss, determine the amount of loss and then reduce losses that have the greatest impact on boiler efficiency. Generally, the most important is heat lost with exhaust gas, and also important is heat is lost through radiation and convection, especially for boilers that are old and which are operated with a flow rate below the design flow rate. In this study, the indirect method is used, where all of the parameter components are determined.

From the results of observations during the energy audit in the boiler unit, the operational description of boiler performance conditions is as follows.

**Table 2**. Steam Energy Balance for each Steam at Boiler Hoken 1,5 Ton/hr

| | | |
|---|---|---|
| **I. Kondisi Operasi** | | |
| Steam Capacity | 1,5 | Ton/hr |
| Operation | 15 | Hr/day |
| Fuel Consumption | 11,13 | Liter/hr |
| Feed Water | 0,1333 | $m^3$/hr |
| | 133,33 | Liter/hr |
| Combustion Lost | 0,00029 | kg water/kg steam |
| **II. Fuel** | | |
| Type | **Diesel Oil** | |
| Density | 870 | kg/$m^3$ |
| | 0,87 | kg/liter |
| Consumption | 11,13 | Liter/hr |
| Calorific value | 9.250 | kcal/liter |
| | 38.702 | kJ/liter |
| **III. Combustion Gas** | | |
| Temp. | 150 | °C |
| Combustion Gas Composition | 11,70 | % $CO_2$ |
| | 3,10 | % $O_2$ |
| Pressure | 0,35 | mBar |
| **IV. Air** | | |
| Temperature | 32 | °C |
| | 305,15 | K |
| Water vapor Pressure (Pv) | 612,24 | mm$H_2O$ |
| | 6,00 | kPa |
| Density | 1,16 | kg/$m^3$ |
| Specific Moisture | 0,04 | kg $H_2O$/kg dry air |
| *M* air | 28,96 | kg/kmol |
| *R air* | 0,29 | kJ/kg K |
| Atmosferic Pressure | 101,33 | kPa |
| **V. Feed Water** | | |
| Flow Rate | 133,33 | Liter/hr |
| Temperature | 80 | °C |
| Electric Load | 14,42 | kW |
| Power Factor | 0,86 | |
| Rpm | 10.490,6 | rpm |
| TDS | 495 | ppm |
| **VI. Steam** | | |
| Pressure | 6 | Barg |
| Temperatur | 165 | °C |
| Flow rate | 0,455 | Ton/jam |
| **VII.. Bolldr surface** | | |
| Surface area | 21,38 | $m^2$ |
| Min Temperature | 38,0 | °C |
| Max Temperatur | 45 | °C |
| **VIII. FD Fan** | | |
| Inlet air Temperature | 35 | °C |
| Electric Load | 31,50 | kW |
| Air Flow Rate | 44.100 | liter/hr |
| Power Factor | 0,88 | |
| Rpm | 45832,50 | rpm |
| **IX. Blowdown** | | |
| Flow Rate | 4,00 | liter/hr |
| Temperature | 165 | °C |
| TDS | 3.500 | ppm |
| Blowdown | 16,5 | % |

Based on these data, boiler performance is calculated indirectly. Calculation of boiler efficiency is done by calculating the energy balance in the attachment. The following is the value of boiler efficiency based on operating conditions using indirect methods.

**Table 3.** Efficiency Analysis of Boiler Hoken 1,5 Ton/hr

| Information | Value |
|---|---|
| **Theoritical air requuirement**<br>[(11.43 x C) + (34.5 x (H2-O2/8)) + (4.32 x S)]/100 | 1.358,51 |
| **% Excess air [Excess Air/(EA)]**<br>[%O2 x 100]/[21-%O2] | 17,32 % |
| **The actual air mass is supplied/L Fuel (AAS)**<br>[1 + EA/100] x Theoretical air | 1.593,78 L/hr |
| **Heat Loss**<br>**Heat loss caused by dry exhaust gases**<br>[m x cp x (Tf-Ta) x 100/ [GCV fuel] | 42,03 % |
| **Heat loss due to water content evaporation to the presence of H2 in fuel**<br>[9 x H2 (584 + 0.45 (Tf - Ta)]/GCV fuel | 0,16 % |
| **Heat loss due to moisture content in the air**<br>[AAS x moisture x 0.45 x (Tf - Ta) x 100]/GCV fuel | 0,35 % |
| **Heat loss due to radiation**<br>[5.67 . ε . A . $T^4$]/GCV fuel | 1,45 % |
| **Heat loss due to convection**<br>[Q = α . A. (Ts - To)]/GCV fuel | 1,615E-06 % |
| **Heat loss due to blowdown**<br>[($m_{BD}$ . ($h_{BD}$ - $h_{FW}$))]/[$m_{BB}$ . $h_{BB}$] | 0,34 % |
| **Countless heat losses** | 2,00 % |
| **Boiler Efficiency** | **53,67 %** |

Based on the table of boiler efficiency analysis above, excess water and heat loss is very high which limits the standard combustion conditions, for optimal percentage diesel fuel that is permitted for excess water is equal to 5-15% and% O2 on combustion gases of 1-3% (see table 3).

**Table 4.** Value Standard of excess air and $O_2$ of Combustion Gas

| Fuel | Optimum Excess Air (%) | Optimum $O_2$ of Stack Gas (%) |
|---|---|---|
| Coal | 20 – 25 | 4 – 4,5 |
| Biomass | 20 – 40 | 4 - 6 |
| Stoker firing | 25 – 40 | 4,5 – 6,5 |
| Oil | 5 – 15 | 1 - 3 |
| LPG | 5 – 10 | 1 - 2 |
| Black Liquor | 5 – 10 | 1 - 2 |

From the results, the process of the Hoken steam boiler has excess water of 17.32% and O2 = 3.1%. This value does not meet the standards of excess air and O2 in the Hoken boiler exhaust gas so that energy use efficiency has not been achieved. Heat loss/heat loss in steam distribution shows a value of 42.03%, this is due to the high air flow for combustion in the boiler. The value of excess water and heat loss has an impact on the low energy use efficiency of 53.67%. Many distribution pipes are exfoliated, pipes that are not isolated, and headers that have not been isolated. At some pipe points, there is also a steam leak that is not as large as it is but because the amount is very large so it can reduce the value of energy efficiency.

There are so many causes of the inefficiency of the combustion system in the boiler. This must also be supported by operators who understand the performance of boiler operations. In commonly boiler design is very essential. Nevertheless, there are some other environmental factors that have an influence on boiler efficiency. Make Understand what they are will help operators to recognize shortcomings in boilers, which will indorse them to solve problems and the system is on a fast target towards optimization. This is five factors that affect boiler efficiency:

a) Excess Air Effect on Boiler Efficiency

All combustion requires excessive air levels. Excess air is formed because the amount of air in the combustion process is greater than the amount theoretically needed for complete oxidation. To ensure complete combustion of the fuel used, the combustion chamber is supplied with excess air. Excess air increases the amount of oxygen to combustion and combustion of fuel. When fuel and oxygen from the air are in perfect balance - combustion is said to be stoichiometric. Combustion efficiency increases with increasing excess air so that the heat lost in excess air is greater than the heat produced by more efficient combustion. Low emission burners, excess air is used to minimize NOx and carbon monoxide production by adjusting the flame temperature inside the burner. Excess air finally absorbs some of the heat from combustion. As a result, this reduces the efficiency of transferring heat to water in the boiler. This problem can be overcome by calibrating boilers at various levels of combustion and regularly [9].

b) Flue Gas Temperature

The stack temperature or exhaust gas temperature measures combustion temperature gas when leaving the boiler. If the temperature of the exhaust gas starts to rise, it indicates that the heat produced by the boiler is less used optimally to produce steam. In other words, the resulting exhaust gas temperature is high but a lot of heat is lost.

How to deal with this is an installed economizer, air heater. This is a solution to overcome heat loss caused by high exhaust gases. These methods are designed to recover heat for the boiler system [10].

c) Radiation and Convection Losses

Radiation and convection loss is the loss of heat from the boiler during the operation. Radiation and convection losses are always happening and cannot be avoided, but can take the right steps to minimize them. Two effective strategies for reducing losses due to radiation and convection are installing insulation on the surface of the kettle and controlling the flow of air for combustion. Utilizing the right insulation method and using the right materials, will increase the efficiency of the boiler because heat loss decreases and the surface temperature decreases. Protect the boiler with insulation so that it does not come into direct contact with the surrounding air to prevent heat loss caused by air flowing above the boiler surface [11].

d) Fuel Specification

The efficiency of the boiler is also influenced by fuel specifications. Overcoming this problem is as easy as setting the right fuel specifications and ensuring that the actual fuel meets the documentation criteria. Fuel specifications must be the most important because of the high hydrogen content of natural gas products. It is important to understand that most hydrogen is converted to water during combustion. This process can produce energy, which is used in the combustion process.
The higher the hydrogen content in combustion gases, the more water produced by combustion. The higher concentration of natural gas and the lower proportion of other gases are more efficient in the combustion process.

e) Ambient Temperature

Ambient temperature is the temperature caused by the boiler operation process which has an impact on the increase in ambient temperature. The ambient temperature is driven by the forced draft fan also has an impact on the calculation of boiler's efficiency. This affects the temperature of the chimney. The net stack temperature is the difference between the temperature of the exhaust gas and the ambient temperature. Although it is tempting to reduce ambient temperature with a lower exhaust gas temperature, a change in temperature of 40 degrees can affect the efficiency of boilers by up to one percent or more.

**B. Steam Distribution System**

In a steam distribution installation, in general the piping system in this pharmaceutical factory is quite good. Heat leaks in pipes generally do not propagate out the surface of the insulation, meaning that the insulation conditions are still quite good. But there are certain points such as CP-PP, CPOB, and Bethalaktam, some of which have not been isolated or damaged insulation. According to the results of the temperature measurements on the pipe without insulation, the average is around 180-200$^oC$ so there is a high probability of too much condensate which affects the increase in the amount of fuel, water and electricity in the boiler performance.

For these conditions, it is necessary to review the entire piping system for the possibility of eliminating some parts such as headers that are actually not needed and need to be installed with air vent and accessories. Actual conditions illustrate that steam leakage occurs because steam traps do not work well on distribution pipes and lagger/topper equipment. The ideal percentage of condensate heat that can be returned from this condition is the water boiling heat at the process pressure coming out of the steam trap, divided by the total heat to generate steam. Based on the results of observations on steam distribution, it is known that there is steam that has a leak [12]

## 4 Discussion

Based on the results of observations and measurements in the field, analysis, and evaluation of the data obtained identified several potential energy savings that can be done. The potential savings can be done by improving the condition of the electrical system, boiler exhaust gas, combustion system, steam distribution, or the implementation of new energy user equipment.

Efforts for improvement must be carried out continuously so that the optimal production process with efficient energy use can be achieved. Based on the results of calculations and analysis, several potential energy savings potentials have been identified. This energy saving potential can increase efficiency on thermal units. The following is the energy-saving potential that can be done by performing in the thermal utility system as follows:

a. $O_2$ composition in the exhaust gas and excess air percentage.

Optimizing the condition of the composition of $O_2$ and excess air in the exhaust gas can be done by setting valve/ damper on the side of the air duct for combustion chamber. Energy losses and energy efficiency opportunities in process of boilers can be related to combustion, heat transfer, avoidable loss, high energy consumption for auxiliary equipment, water quality, and blowdown.
The various opportunities for energy efficiency in the boiler system can be linked to controlling the temperature of the chimney, preheating feed water using an economizer, combustion air preheater, minimizing imperfect combustion, controlling excess air, avoiding radiation heat loss and convection, automatic blowdown control, reduction crust formation, and soot loss, reduction of steam pressure in the boiler, variable speed control for fans, blowers and pumps, control of boiler load, proper boiler scheduling, boiler replacement.

b. Exhaust gas sensor Installation (flue gas analyzer)

Combustion efficiency in boilers is usually seen also from the exhaust gas in the chimney ($O_2$ & $CO_2$) [13]. In this company, when the boiler system is observed, there is no exhaust gas sensor so that its efficiency is not controlled or when the air is over burning, it can be difficult to set the combustion air supply. Therefore, to improve combustion performance system in the boiler, it is necessary to install a gas sensor analyzer programmed with an ID & FD fan. So that the efficiency is monitored and set automatically.

c. Repairing the steam distribution channel so that the steam generated from the boiler system can be utilized optimally

## Summary

The results of measurements and calculations obtained boiler efficiency of 53.67% where the factors that cause the low efficiency of this boiler are the high excess water by 17.32% and heat loss from dry exhaust gas by 42.03%. The solution is done by controlling excess air by regulating the air entering the combustion chamber. In this way, energy savings can be increased by 15%.

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