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A review on boilers energy use, energy savings, and emissions reductions

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ABSTRACT

Boiler is a widely used steam generating system in industries and power plants. A significant portion of the world energy consumption is being used in boilers. A small improvement on the boiler efficiency will help to save a large amount of fossil fuels and to reduce CO_2 emission. This study describes the amount of energy used in boilers, ways employed to evaluate their energy efficiency, losses occurred and their causes, ways of waste heat recovery and minimizing heat loss using technologies, role of maintenance activities, and technical education to make people aware of the energy usage. Latest published literature on the above mentioned topics which includes PhD and MSc theses, journal articles, conference proceedings, reports and web materials have been reviewed and reported. It is found that a substantial amount of energy is wasted through high temperature flue gas or exhaust of the boiler. Also, some other unavoidable losses occurr due to various reasons. However, waste heat could be recovered using different technologies as a useful form of energy such as electricity, heat, refrigeration effect, etc. The efficiency of the boiler can be improved by doing scheduled maintenance work, which helps to run a boiler at its highest efficiency. In order to create awareness about energy use, education programs and seminars need to be arranged on regular basis for the staff involved. This will help them to understand the importance of the energy as being used in the boiler system as well as the impact of their actions during the operation of the boiler.

1. Introduction

Boilers are pressure vessels used for heating water or producing steam to provide heating facility in industries and to generate electricity through driving steam turbines. Boilers are also used for providing space heating for buildings as well as for producing hot water and steam required by users such as laundries and kitchens [1]. Fossil fuels such as coal, gas, oil etc., and nuclear energy, are being used to generate a major portion of world's electricity and generally boilers are the best choice to convert these types of energy into electricity [2,3]. Hence, it is obvious that enhancement of the efficiency of a steam boiler by just a small fraction, will reduce a vast amount of energy consumption in electricity generation. Again, despite the depletion of fossil fuel reserves and environment protection issues, the oil, natural gas and coal demand is expected to rise up to 47.5%, 91.6%, and 94.7%, respectively between 2003 and 2030 [4]. Moreover, most of the industrial heating systems employ boilers to produce hot water or steam. Therefore, an efficient boiler has also a significant influence on heating-related energy savings [5]. A substantial amount of energy can be saved by adopting energy saving measures and by improving the overall boiler efficiency.

In the combustion chamber of a boiler, fossil fuel burnt and the produced heat is transferred through hot flue gas to water. As the hot flue gas transfers heat to water by convection heat transfer, a major portion of heat is lost through the outgoing flue gas. As the temperature of the flue gas leaving a boiler typically ranges from 150 to 250 °C, about 10–30% of the heat energy is lost through the process [6,7]. Other heat losses from a boiler are radiation, blow-down, fly ash and bottom ash losses [8,9]. in order to run a boiler plant at its maximum efficiency, it is necessary to identify the major source of energy wastage

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Nomenclature

AAS	Actual Air supply (kg)
AF	Air fuel ratio (kg/kg)
AC	Alternate Current (A)
C	Carbon
CO	Carbon mono oxide
CO2	Carbon dioxide
C_p	Specific heat of moisture (kJ/kgK)
C_{pg}	Combustion gas specific heat (kJ/kgK)
EA	Excess air
GCV	Gross Calorific Value (kJ/kg)
H	Hydrogen
HHV	Higher heating value (kJ/kg)
K	Constant
LHV	Lower Heating Value (kJ/kg)
L_{stack}	Energy loss through stack
M	Mass of moisture in fuel (kg)
m_a	Mass flow rate of air (kg)
m_f	Mass flow rate of fuel (kg)
m_g	Mass of combustion gas (kg)
N	Nitrogen
O2	Oxygen
ppm	Parts per million
RTD	Resistance Temperature Detector
TDS	Total Dissolved Solids
T_a	Temperature of air (K)
T_C	Combustion Temperature (K)
T_f	Temperature of fuel (K)
T_{stack}	Stack temperature (K)
VFD	Variable Frequency Drive
VSD	Variable Speed drive
η	Efficiency (%)

and recover the energy which is wasted.

The efficiency of boiler is the ratio of the net amount of heat which is being absorbed by the generated steam to the net amount of heat supplied to the boiler. This can also be determined by subtracting the net amount heat lost from the boiler from the net amount of heat supplied to the boiler [10]. Hence to improve the boiler efficiency, the amount of heat being wasted from the boiler needs to be minimized by optimizing some parameters such as excess air, fuel flow rate, steam demand, etc. [11]. To ensure complete combustion, a boiler is to be provided with more combustion air than what is theoretically suggested. Otherwise, there will be a rapid buildup of carbon monoxide in the flue gas, and in extreme cases, smoke will be produced. On the other hand, too much excess air increases the quantity of unnecessary air that is heated and exhausted at the stack temperature [12]. A typical heat balance in a boiler is shown in Fig. 1.

According to Fig. 1, 10–30% of the input heat is wasted through the flue gas and this is the highest source of heat loss in the boiler system. Since most of the heat is being wasted through the high temperature flue gas, the recovery of heat from high temperature exhaust can result in significant energy savings [1,13,14]. Harnessing the waste heat from the high temperature flue gas could be a huge energy savings potential for a boiler system. However, the boiler efficiency can be improved by minimizing this loss supplying optimizing excess air ratio using a VSD (variable speed drive) [15–17]. A VSD is used on the fan motor to change excess air ratio. Fig. 2 shows boiler efficiency with the flue gas temperature reduction.

Fossil fuel consumption is directly related to the emission of CO_2. Environmental protection regulations insist to reduce the emission of CO_2 [19–21] as this is significantly responsible for the greenhouse effect. Hence, to reduce the emission of CO_2 and consumption of fossil fuels, the efficiency of the current energy systems must be improved. There are many ways to reduce energy and heat consumption and carbon dioxide emissions [21–23]. Thermal efficiency of the power plant is around 30.12% for the gross generator output and the maximum energy loss occurs in the boiler. As a result, the performance of the power plant could be greatly improved by improving the performance of the boiler, since this will contribute to the largest improvement to the plant's efficiency [24].

From the literature, there is no comprehensive review on energy use, savings, associated bill savings and avoided emission, along with cost benefit analysis. It is expected that this study will fill that gap. Furthermore, the study could provide important guidelines for future research and development allocations and energy projects to reduce boiler energy use. It will create awareness among the industrial energy users to reduce the boilers energy uses along with environmental pollution reduction.

2. Energy used in boilers

Most of the major industrial processes use steam. USA alone is consuming and burning about 37% of the total fossil fuel to produce steam. This steam has been used in different processes such as heating, concentrating and distilling liquids, drying, etc. Major energy intensive industries allocate significant part of their primary fuel consumption to steam generation: food processing (57%), paper and pulp (81%), petroleum refining (23%), chemicals (42%), and primary metals (10%) [9]. Saidur and Mekhilef [25] reported that 20% of total energy consumption is used in process heating in a rubber producing industries in Malaysia. Fig. 3 shows different types of energy consumption along with process heat in rubber industry in Malaysia. In 2012, U.S. electric utilities converted 38 billion GJ_{en} of coal, natural gas, and nuclear energy into 12.3 billion GJ_{elec} of electricity [26], an average efficiency of 32%. Electricity generation at these plants is performed by combustion fuel (e.g., coal and natural gas) or utilizing nuclear reactions to heat a fluid. The resulting hot fluid drives the blades of a turbine and its associated generator, thereby converting thermal energy into mechanical energy and then electric energy [27–29].

To supply steam for a textile plant significant amount of energy is required. Fig. 4 shows energy consumption for generating steam and other types of final energy consumption in a textile plant in the U.S. The percentages may vary from one country to another, but this figure gives a hint of final energy end-use in the textile industry. In the U.S. textile industry motor-driven systems and steam generation systems have the highest share of the end-use energy use and each accounts for 28% of total final energy use [30].

3. Energy audit for boilers

Energy audit is a systematic approach to investigate industrial

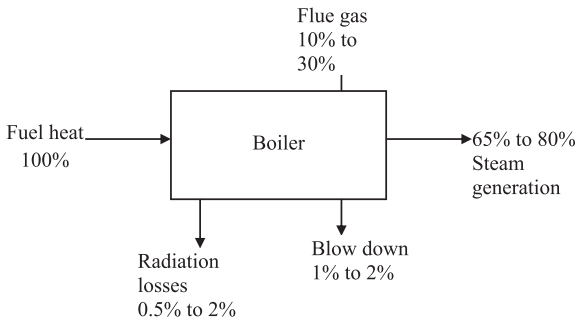

Fig. 1. Typical Heat Balance of a boiler [1].