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An Overview of the Energy Savings, Utilization, and Emission Reductions of Boilers

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Abstract- Industries and power plants use boilers extensively as a steam generating system. Boilers use a substantial amount of the world's energy supply. Much more fossil fuel can be saved and CO2 emissions can be decreased with even a slight increase in boiler efficiency. This paper outlines the energy consumption of boilers, the methods used to assess their energy efficiency, the losses that have occurred and their reasons, the role that maintenance activities play in preventing heat loss, the quantity of waste energy recovered, and the methods of raising public awareness of energy consumption. On the aforementioned subjects, the most recent published literature has been examined and reported. This includes journal articles, PhD and MSc theses, conference proceedings, reports, and online resources. The high temperature flue gas or boiler exhaust is discovered to be a significant source of energy loss. Also, for a variety of reasons, there are certain other inevitable losses. However, waste heat may be captured and used to provide power, heat, refrigeration effect, and other useful forms of energy utilizing a variety of methods. By doing planned maintenance, one may increase a boiler's efficiency and keep it operating at peak performance. Staff members must regularly participate in education programs and seminars aimed at raising knowledge about energy consumption. As a result, they will be better able to comprehend the significance of the energy utilized in the boiler system and the effects of their activities on it.

Introduction

Boilers are pressure vessels that are used to heat water or produce steam for industrial heating purposes and to power steam turbines to produce energy. In addition to producing hot water and steam that are needed by users in areas like laundry rooms and kitchens, boilers are also utilized to provide space heating for buildings [1]. Boilers are often the greatest option for converting fossil fuels like coal, gas, oil, and so forth into electricity. Fossil fuels account for a large amount of the world's power production [2, 3].Consequently, it is clear that even a tiny increase in boiler efficiency can result in a significant reduction in the energy used to generate power. Once more, the demand for oil, natural gas, and coal is predicted to increase to 47.5%, 91.6%, and 94.7%, respectively, between 2003 and 2030 [4], despite the depletion of fossil fuel supplies and environmental protection concerns. In addition, boilers are used in the majority of industrial heating systems to generate steam or hot water. Consequently, heating-related energy savings are also greatly impacted by an efficient boiler [5]. By implementing energy-saving strategies and raising boiler efficiency overall, a significant amount of energy may be saved.

Fossil fuel burns in the combustion chamber of a boiler, and the heat that is produced is transmitted to water through hot flue gas. A significant amount of heat is lost through the outgoing flue gas when the hot flue gas uses convective heat transfer to transmit heat to the water. About 10-15% of the thermal energy is lost throughout the process, since the temperature of the flue gas exiting a boiler normally varies between 150 and 250 °C [6, 7].Radiation, blow-down, fly ash, and bottom ash losses are other ways that a boiler might lose heat [8, 9]. Finding the main source of energy loss and recovering that energy is essential to operating a boiler plant as efficiently as possible.

The difference between the net quantity of heat given to the boiler and the net amount of heat absorbed by the steam it produces is the boiler's efficiency. In order to calculate this, you may additionally deduct the net amount of heat provided to the boiler from the net amount of heat lost [10]. Therefore, in order to increase boiler efficiency, it is necessary to reduce the amount of heat lost from the boiler by optimizing a number of factors, including extra air, fuel flow rate, steam demand, and so on [11]. More combustion air than is theoretically suggested must be supplied to a boiler in order to guarantee full combustion. In the absence of such measures, the flue gas will quickly accumulate carbon monoxide, and in severe situations, smoke may be released. Nonetheless, an excessive amount of extra air raises the amount of air that is not needed and is burned at the stack temperature [12].A boiler's atypical heat balance is seen in Figure 1.

The largest source of heat loss in the boiler system, as shown in Fig. 1, is the 10-15% of input heat that is squandered through the flue gas. Recovering heat from high temperature exhaust can save a large amount of energy since the high temperature flue gas wastes most of the heat [1, 13, and 14]. A boiler system may be able to save a significant amount of energy by using the waste heat from the high temperature flue gas. On the other hand, a variable speed drive (VSD) may be used to optimize the surplus air ratio and minimize this loss, hence increasing boiler efficiency [15–17]. The fan motor's VSD adjusts the ratio of surplus air.
The amount of CO2 released is closely correlated with the use of fossil fuels. Since CO2 emissions are mostly to blame for the greenhouse effect; environmental protection rules require a reduction in CO2 emissions [19–21]. As a result, increasing the efficiency of the present energy systems is necessary to lower CO2 emissions and fossil fuel usage. Reducing energy and heat consumption as well as carbon dioxide emissions can be accomplished in a number of ways [21–23]. The boiler has the most energy loss, and the power plant's thermal efficiency is around 30.12% of the total generator output. Consequently, while increasing boiler performance would lead to the biggest increase in plant efficiency, power plant performance might be significantly enhanced [24].
The literature does not provide a thorough examination of energy consumption, savings, related bill reductions, prevented emissions, or cost-benefit analysis. It is anticipated that this research will close that gap. Additionally, significant recommendations for future energy initiatives and research and development funding aimed at lowering boiler energy use may come from this study. The industrial energy users will become more conscious of the need to cut back on boiler energy use in addition to lowering environmental pollutants.

Power utilized in boilers
Steam is used in the majority of important industrial activities. Approximately 37% of all fossil fuels are used and burned in the USA alone in order to create steam. This steam has been used in a variety of operations, including drying, heating, and condensing and distilling liquids. The following major energy-intensive sectors devote a sizeable portion 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]. In Malaysia's rubber-producing sectors, process heating accounts for 20% of overall energy consumption, according to Saidur and Mekhilef [25].Figure 3 illustrates various forms of energy consumption and process heat in the Malaysian rubber industry. The average efficiency of the conversion of 38 billion GJen of coal, natural gas, and nuclear energy into 12.3 billion GJelec of electricity was achieved by U.S. electric utilities in 2012 [26]. These plants generate electricity by heating a fluid through nuclear reactions or by burning fuel (such as coal and natural gas). In order to transform thermal energy into

mechanical energy and subsequently electric energy, a turbine and its related generator are powered by the hot fluid that results [27–29].

A considerable quantity of energy is needed to supply steam for a textile mill. A textile factory in the United States is depicted in Fig. 4 with its energy usage for steam generation and various forms of final energy consumption. The figures may differ across different countries, but this one provides an indication of the textile industry's ultimate energy end-use. Both steam generation and motor-driven systems account for 28% of the total final energy used in the U.S. textile sector, which is the largest percentage of end-use energy usage [30].

Boiler energy audit

An organized method for examining industrial energy use and pinpointing the precise locations of energy waste is energy auditing. An organization may use this tool to analyse and comprehend how much energy it uses. In order to increase energy efficiency, decrease energy waste, and drastically lower energy expenses, it is also helpful to plan energy consumption and allocate budgeted energy to various organizational departments [31, 32].

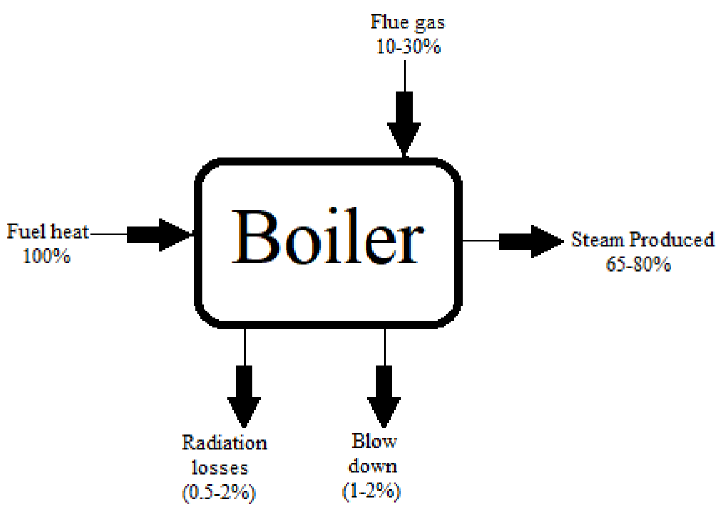

Diagram-1. The Average Heat Balance of a Boiler

One of the main components of a production process and frequently a significant plant expense is energy usage. In an effort to balance the overall energy intake with its usage, an energy audit helps a facility identify and quantify all of its energy consumptions. Energy audits may therefore be applied as a methodical approach to the formulation of energy management policies. An efficient instrument for developing and pursuing an all-encompassing energy management program is the energy audit study. Saidur provides a thorough analysis of the several forms of energy audits, their goals, advantages, and procedures [31, 33].

Resources for Energy Audits

A walkthrough tour, talks with plant management, and operator interviews precede the energy audit process. A walkthrough tour, facility utility bills for things like power, gas and water, among other things, and other operational data assist in familiarizing oneself with the building's functioning and pointing out any obvious inefficiencies or waste of energy. To assess the facility's energy demand rate structures and energy use profiles, the auditor needs utility invoices for a 12- to 36-month period. But additional specific information about facility operations is needed in addition to a thorough energy audit. The following tools are required in order to get boiler operation data.

Flow meter-

To precisely quantify the flow of water and steam that is saturated, superheated, and moist. Exhaust gas analyzer- to as precisely as possible measure the amounts of various polluting gases and the efficiency of combustion at the boiler's chimney.

Pressure probe-

The amount of pressure required in a boiler system to achieve the highest possible combustion efficiency varies depending on the location.

Clamp-on Power meter-

Clamp on power meters can be used to monitor power consumption, current consumption, load factor, and power factor by various electrically powered systems. The meter's clamp-on function allows for the recording of measures without interfering with regular operations.

Portable Tachometer-

Any spinning component of the boiler system may have its speed measured with a portable tachometer. Because they are easier to measure, optical type tachometers are preferred.

Sensor for thermocouples-

Thermometers and thermocouple sensors are employed in many locations to monitor temperature. The most widely used temperature measurement sensors are thermostats and RTDs. Temperature sensors should be linked to a data logger in order to store the data. The temperature of a portion of the system that thermocouple sensors cannot reach can also be measured using an infrared thermometer or thermal image camera.

Recorder of Data-

For extended periods of time, different kinds of system parameters must be collected. Data loggers are used to capture information on temperatures at various boiler locations, motor power consumption, and the composition of flue gas over time. To measure the size of boilers and steam pipes as well as other crucial system characteristics, measuring tools such as measuring tapes and sliding calipers are required. To aid in the identification of the distinctive properties of the fuel, a few laboratory tools are also required. The determination of heating value, final analysis, and thermo gravimetric analysis are often utilised laboratory-related tasks required in energy audits. A thorough financial analysis is also required to determine the amount of investment, operational cost reductions, and implementation expenses.

Boiler Losses-

Heat loss is a major factor in the thermal efficiency of boilers that heat thermal oil or produce superheated steam. The methods of heat loss differ based on the fuel type, boiler type, operation circumstances, etc. According to Bujaketal [34], heat loss from boilers using gaseous and oil fuels happens through the chimney, through the boilers outside surface to the environment, and as a result of incomplete combustion. Technical and operating factors also cause each boiler to lose heat, which affects its efficiency.

According to Gupta et al. [35], radiation, blow down, combustion of hydrogen, unburned carbon in waste, dry flue gas, moisture in fuel, and these factors all contribute to heat loss in coal-fired boilers. Open condensate tanks may cause energy loss [22, 36]. Depending on the kind of fuel and the boiler's intended use, boiler energy efficiency can range from 20% to 92% [24].According to HHV, the thermal efficiency of boilers powered by coal ranges from 81% to 85%, that of oil from 78% to 81%, and that of gas from 76% to 81%. Boilers that are not properly maintained might lose up to 30% of their initial efficiency [37]. High air/fuel ratios, under-rated steam production, surface thermal losses, and high flue gas temperatures are the main causes of heat loss [38]. All parts of the boiler system lose heat. There are four major categories into which all losses can be placed.

- Heat taken away by dry gases (water vapour excluded).
- Heat transported away by hot water vapour, including late-night heat and sense heat.
- Heat loss via incomplete combustion, unburned carbon in the fuel, conduction, radiation, and convection losses from the outside surface.
- Loss on blow-down [39].

Heat loss from the stack-

The stack gas in a boiler is where the majority of energy loss happens. The primary determinants of heat loss assessment are the boiler's output temperature and stack gas volume. As a result, lowering any of these factors will lower the heat loss. The temperature of stack gas would need to be lowered to boiler ambient temperature in order to avoid stack loss. However, these losses are unavoidable because of the economic impossibility and limitations of the heat transfer principle [8, 39].A reduction in heat transfer to the steam and an increase in pumping needs can be attributed to leaks in the flue gas duct, excess air supply from a forced draft fan operating at a high frequency and boiler leaks [30, 37]. The following actions can reduce the amount of heat lost via stack gases:

- Excessive personalization
- Preserving a pristine heat transfer area
- Including flue gas recovery systems

Because there is less surplus air, the volume of stack gas is decreased. As a result, there is less stack gas, which gives the flue gas more time to absorb heat and lowers the temperature of the flue gas. This lowers the flue gas velocity. Boilers range in efficiency from 75% to 90% on average, thus it is important to find strategies to reduce the 10–25% energy losses that come from this [40].

Radiation and conduction losses-

Auxiliary equipment, the steam distribution pipes, and the surrounding regions are all at different temperatures from the outside of the boiler. Because of this, heat is lost from the boiler systems' heated surfaces by radiation, convection, and conduction. Thermal conductivity, thickness, and quality of the insulation all affect how much heat is lost. The temperature of the heated surface determines how much heat is lost. Insulation material that is sufficiently resistant to heat transfer should be used to cover hot surfaces in order to reduce heat loss [35]. It is also important that the insulation is in excellent condition and has an appropriate thickness.

Heat loss at low loads as well. In comparison to the overall loss as indicated in, heat loss via radiation and convection for a typical boiler running at full load is just approximately 2%.

Losses from short cycling boilers-

Short cycling of the boiler Loss happens when a large boiler is chosen for a particular process with a modest heating need and an unfulfilled plan for plant or process expansion [41, 42].It is typical in big enterprises for a single boiler to feed steam to several manufacturing lines, even while the majority of the production lines are not currently in use. Oversized boiler selection may result from space heating or HVAC load calculation that ignores additional heat sources, such as lighting, equipment, or people, as well as heat loss through the structure. This large boiler quickly meets the building's heating needs, which causes the boiler to short cycle or maybe continue producing steam at a low fire rate. On the other hand, boiler brief cycling or low fire rate operation result in a reduction in boiler thermal efficiency [43].

This reduction in efficiency is brought about by the boiler's fixed losses being magnified when it is operated at a low load. Radiation loss rises to folds at 50% loading situation compared to full load condition. Pre- and post-purge procedures result in an extra heat loss. In order to eliminate any potentially stored flammable gas combination, the fan is employed to blow air through the boiler. Heat is lost from the boiler during purging because the purged air is heated [44].

Multiple small boilers and a facility with a total boiler rated capacity that can match the maximum projected load are necessary to minimize boiler short cycling loss [44]. Without sacrificing boiler efficiency, an operator can use several small boilers to supply the variable demand for steam. In situations when steam demand is seasonal, having many tiny boilers can be highly efficient. In times of low demand, small boilers can be used to produce steam instead of running huge boilers continuously [41]. The many tiny boiler system needs an automated controller to divide the load among the boilers efficiently. Energy may be installed in smaller boilers to improve the high-fire duty cycle, with an average payback period of 1.9 years (U.S. DOE-IAC, 2006) [30]. This is made possible by efficient regulating numerous boilers and pipe components.

Leaks in steam-

Process equipment, flanges, connectors, traps, valves, and pipelines can all leak steam. For some steam distribution systems, it may be significant. The size and operating pressure of an aperture determine how much steam leaks from it[1]. The majority of the overall loss might be traced to a limited number of big steam or condensate leaks, according to a survey done by McKay et al. [45] to find and measure the losses in a plant. The primary boiler had an efficiency of 80%, but they also discovered that 25% of live steam might flow via failing steam traps.

Energy-saving boiler techniques-

Regulagadda et al.'s study [7] looked for and located the mechanisms involved in the loss of energy in a coal-fired steam turbine. Maximum energy destruction in a coal-fired steam turbine power plant was discovered to occur in the boiler. Consequently, increasing boiler performance is necessary to boost the efficiency of the steam turbine power plant, which leads to the biggest gain in the plant's performance [7].Below are some potential energy-saving measures for the steam distribution systems:-

Excess air control-

Burning the supplied fuel requires the supply of combustion air to the combustion chamber of a boiler. Other portions of the air absorb sensible heat from combustion, which is expelled together with combustion products down the chimney as a stack loss. Only oxygen from the supplied air participates in the combustion process. Consequently, to reduce stack loss, the volume of combustion air should be as low as feasible. Only theoretical air, however, cannot guarantee full fuel combustion due to certain restrictions. Provided combustion air must exceed the theoretical need in order to attain full combustion. Incomplete combustion of fuel might lead to greater percentages of CO in the flue gas or unburned carbon in the ash. Thus, to reduce the amount of dry flue gas loss, a boiler should be run with the maximum amount of extra air.

Increasing the efficiency of combustion-

The release of a fuel's energy content through combustion reaction and conversion into useable heat is directly correlated with combustion efficiency. It may be determined by monitoring the oxygen, carbon monoxide, and exhaust temperature in flue gas. Therefore, increased emissions of unburned pollutants such CO and soot are also a result of reduced combustion efficiency [70]. In a perfect world, a specific volume of air is needed to react fully with a given volume of fuel. Proper fuel mixing cannot be achieved in real combustion; hence, "excess" air must be offered in order to burn the fuel fully. Reduced air supply will result in unburned carbon in fly ash or incomplete combustion, which releases carbon dioxide. As a result, some of the fuel's heat content is lost.

A considerable quantity of heat can be produced by the unburned carbon and carbon monoxide reacting further. However, an excessive amount of surplus air raises the volume of flue gas, which in turn raises the concentration of oxygen in the flue gas and thereby increases stack loss. Consequently, it is best to optimize the quantity of surplus air by analyzing the carbon monoxide or oxygen concentrations in flue gas [41].

The lowest amount of fair that contains the necessary amount of oxygen for a certain fuel to burn completely is known as the stoichiometric air.

Heat Recovery in Flue gases-

The temperature of boiler exhaust varies between 150 and 250 °C [75] because of the restricted region for heat transmission between the combustion product and water or steam or the condensation of flue gas. Because of this, boiler exhauster gases lose a significant quantity of heat energy. High temperature flue gas may lose 10-15% of the energy input [6].Therefore; recovering a portion of the flue gasses overall heat content might increase boiler efficiency. This heat can be utilised as a driving heat source for other devices, such an absorption chiller, or to warm the boiler's feed water and combustion air.

Conclusions-

In many sectors, boilers are frequently employed as steam generating devices for heating operations. Boilers heat up steam for steam turbines in thermal power facilities. Boilers are discovered to be utilised globally to support power generating and heating processes, accounting for a sizeable amount of global energy consumption. But boiler efficiency is usually between 75 and 90 percent, and the remaining energy is squandered as various types of wasted heat. Energy audits are a useful tool for assessing the boiler's efficiency and the quantity of heat it loses. In order to determine the possible source of waste heat, this aids in quantifying the quantity of heat lost through various sources. Taking steps to limit the possibility of waste heat sources can increase the boiler's efficiency.

There are other methods for heat loss from the boiler, but among them all, stack gas loss is the main one. While it is not possible to completely remove this loss because to the limited acid dew point of stack gas, it may be minimized by recovering waste heat from the boiler exhaust and using it inside the boiler system. In order to run the boiler efficiently, hot water is removed from the steam drum, which results in blow downs and boiler short cycles, among other causes of heat loss. But while hot water is being drained from the steam drum, too much brief cycling and blow-down result in increased heat loss. Fuel and combustion air quality, namely fuel moisture and air moisture, are responsible for some losses. For this moisture to evaporate and combine with the exhaust gas, heat is required.

This prevents heat transmission from the high-temperature combustion product to the water because incomplete combustion results in unelaborated fuel energy. Conduction and radiation heat loss also comes from the un insulated surface of the boiler, fouling, and scaling. In this study, the literature's causes, consequences, and suggested treatments for the causes of heat loss are examined.

In this study, boiler energy-saving techniques have also been thoroughly examined and addressed. Numerous energy-saving strategies have been examined, including condensate recovery, excessive air management, increasing combustion efficiency, and using the waste heat content of flue gas. A variable speed-driven ID fan might be used to maintain an optimal amount of extra air. Optimized surplus air combined with a VSD-operated ID fan uses less electricity, which lowers stack gas loss by lowering stack gas volume. A well-designed nozzle or combustion process with less extra air used can increase combustion efficiency. Much energy may be saved by utilising the steam trap's appropriate operation and condensate recovery. Lastly, heat recovery systems have the potential to recover waste heat from boiler exhaust and utilise that heat to produce power or refrigeration. Recovered heat can also be utilised to warm the system's feed water or combustion air. Maintaining a boiler properly also contributes to energy conservation and optimal boiler performance. Cleaning of the water and fire side heat transfer surfaces is necessary to optimize the heat transfer from flue gas to water and minimize the heat loss in other areas of the boiler. During maintenance, it is necessary to verify that other equipment is operating as intended. Additionally, it was necessary to continuously disseminate information through education, awareness, seminars, or conferences among technical personnel in order to enhance people's attitudes and values around energy consumption.

Suggestions for future research-

This study concentrated on the energy needed by the boiler to produce steam for various uses, the reasons behind heat loss, and potential energy-saving measures for the steam generation system. An energy audit might be performed to determine how much heat is wasted from a boiler or how efficient it is when functioning. Therefore, this research includes the process for conducting an energy audit at the steam producing facility. But the majority of boilers have been running without a regular energy audit. Even if the energy loss in various new boiler components is within the acceptable range, energy loss is expected to rise as the boiler's operating time increases. In order to pinpoint the main causes of energy loss, the boiler's energy flow must be audited at certain intervals.

Many factors contribute to the majority of energy loss, which may be reduced by employing technologies or by implementing various corrective measures. Experimental research on retrofitting these technologies is necessary, and end users may benefit from more technical advancements in these areas. Additionally, those responsible for operating boilers and other non-technical workers must be well trained and informed on fuel prices and the effects of fuel usage.

References-

[1] Jayamaha L. Energy-efficient building systems: green strategies for operation and maintenance. McGraw Hill Professional; 2006.

[2] (EIA), International energy annual. Online, retrieved [cited 2009 3rd January2009]; 2007.

[3] Statistics UEH. Breakdown of Electricity Generation by Energy Source [cited 201521.09.2015]; Available from: ⟨http://www.tsp-data-portal.org/Breakdown-of-Electricity-Generation-by-Energy-Source#tspQvChart⟩; 2015.

[4] Som S, Datta A. Thermodynamic irreversibilities and exergy balance in combustion processes. Progress Energy Combust Sci 2008;34(3):351–76.

[5] Ganapathy V. Industrial boilers and heat recovery steam generators: design,applications, and calculations. CRC Press; 2002.

[6] Saidur R, Ahamed JU, Masjuki HH. Energy, exergy and economic analysis ofindustrial boilers. Energy Policy 2010;38(5):2188–97.

[7] Regulagadda P, Dincer I, Naterer GF. Exergy analysis of a thermal power plantwithmeasuredboilerandturbinelosses.ApplThermEng2010;30(8–9):970–6.

[8] ERC I. How to Save energy and money in boilers and furnace systems. Energy Rescent (ERC) 2004.

[9] Einstein D, Worrell E, Khrushch M. Steam systems in industry: energy use andenergy efficiency improvement potentials. Lawrence Berkeley NationalLaboratory; 2001.

[10] Basu P, Kefa C, Jestin L. Boilers and burners: design and theory. Springer Science &Business Media; 2012.

[11] Kouprianov V, Chullabodhi C, Kaewboonsong W. Cost based optimization ofexcessairforfueloil/gas-firedsteamboilers.IntEnergyJ2007;21(2).

[12] Ozdemir E. Energy conservation opportunities with a variable speed controller in aboiler house. Appl Therm Eng 2004;24(7):981–93.

[13] BeggsC. Energy: management, supply and conservation. Routledge;2010.

[14] Yeh S, Rubin ES. A centurial history of technological change and learning curves for pulverized coal-fired utility boilers. Energy 2007;32(10):1996–2005.

[15] Mecrow B, Jack A. Efficiency trends in electric machines and drives. Energy Policy2008;36(12):4336–41.

[16] Bayindir R,SagirogluS, ColakI.An intelligent power factor corrector for power system using artificial neural networks.ElectrPowerSystRes2009;79(1):152–60.

[17] ColakI, BayindirR,SefaI. Experimental study on reactive power compensation using a fuzzy logic controlled synchronous motor. Energy Convers Manag2004;45(15):2371–91.

[18] Bonaros V. etal. Analysis of the energy and costsavings caused by usingcondensing boilers for heating dwellings in Greece. In: Proceedings of the 5thInternationalConferenceonAppliedEnergyICAE2013,Pretoria,Paper;2013.

[19] Jorgenson DW, Wilcoxen PJ, Reducing . US carbon emissions: an econometricgeneralequilibriumassessment.ResourEnergyEcon1993;15(1):7–25.

[20] JorgensonDW,WilcoxenPJ,Reducing.UScarbondioxideemissions:anassessmentofdifferentinstruments.JPolicyModel1993;15(5):491–520.

[21] Glaeser EL, Kahn ME. The greenness of cities: carbon dioxide emissions andurban development. J Urban Econ 2010;67(3):404–18.

[22] Bujak J. Minimizing energy losses in steam systems for potato starch production. JClean Prod 2009;17(16):1453–64.

[23] Hoffert MI, et al. Advanced technology paths to global climate stability: energy fora greenhouse planet. science 2002;298(5595):981–7.

[24] Regulagadda P, Dincer I, Naterer G. Exergy analysis of a thermal power plant with measured boiler and turbine losses. Appl Therm Eng 2010;30(8):970–6.

[25] Saidur R, Mekhilef S. Energy use, energy savings and emission analysis in theMalaysian rubber producing industries. Appl Energy 2010;87(8):2746–58.

[26] Agency USEI. Form EIA-923 Detailed Data [cited 2016 25.1.2016]; Available from:⟨http://www.eia.gov/electricity/data/eia923/⟩; 2015.

[27] Gingerich DB, Mauter MS. Quantity, quality, and availability of waste heat from United States thermal power generation. Environ Sci Technol2015;49(14):8297–306.

[28] Moran MJ, et al. Fundamentals of engineering thermodynamics. John Wiley&Sons; 2010.

[29] BlackV,et al.Power plant engineering.NewYork:InternationalThomson;1996.

[30] Hasanbeigi A. Energy-efficiency improvement opportunities for the textileIndustry. Lawrence Berkeley National Laboratory; 2010.

[31] Bhatt MS. Energy audit case studies I—steam systems. Appl Therm Eng2000;20(3):285–96.

[32] Fromme JW. Energy conservation in the Russian manufacturing industry. Potentials and obstacles. Energy Policy 1996;24(3):245–52.

[33] Saidur R. A review on electrical motors energy use and energy savings. Renew Sustain Energy Rev 2010;14(3):877–98.

[34] Bujak J. Mathematical modelling of a steam boiler room to research thermal efficiency. Energy 2008;33(12):1779–87.

[35] Gupta RD, Ghai S, Jain A. Energy Efficiency Improvement Strategies for Industrial Boilers:a CaseStudy.JEngTechnol2011;1(1):52.

[36] Bujak J. Energy savings and heat efficiency in the paper industry: a case study of a corrugated board machine. Energy 2008;33(11):1597–608.

[37] Einstein DW, Ernst Khrushch. Marta, Steam systems in industry: energy use andenergyefficiencyimprovementpotentials.LawrenceBerkeleyNationalLaboratory; 2001.

[38] Kaya D, Eyidogan M. Energy conservation opportunities in an industrial boilersystem. J Energy Eng 2010;136(1):18–25.

[39] KilicaslanI, Ozdemir E. Energy economy with a variable speed drive in anoxygentrim controlled boiler house. J Energy Resour Technol 2005;127(1):59–65.

[40] Showers G. Boiler operation efficiency: insights and tips. Heat/Pip/air Cond Eng2002;74(11):53–6.

[41] ⟨www.oit.doe.gov⟩.200920/11/2009].

[42] ⟨http://oee.nrcan.gc.ca/industrial/equipment/boilers/operation.cfm?Attr=24⟩.

[43] LossesC,MinimizeBoilerShortCyclingLosses.

[44] LossesMBSC,EnergyTips–Steam.

[45] McKayG,HollandCR.Energysavingsfromsteamlossesonanoilrefinery.EngCosts Prod Econ 1981;5(3–4):193–203.

[46] Ltd LEP. BEST PRACTICE GUIDE FOR IMPROVING ENERGY EFFICIENCY OFFOODMANUFACTURING PLANTSIN SINGAPORE.2016[cited; Available from:⟨http://www.e2singapore.gov.sg/DATA/0/docs/Resources/Industry/FMBS

%20Best%20Practice%20Guide.pdf⟩; 2017.

[47] Conservation CIPfE, Dockrill P, Ontario . Boilers and Heaters: improving Energy Efficiency. CIPEC; 2001.

[48] DOE-OIT U. Use Feedwater Economizers for Waste Heat Recovery. Steam TipSheet 3. January 2006. US Department of Energy, Washington, DC, USA. www1.eere. energy. gov/industry; 2006.

[49] ⟨http://www.emerald energy.ie/info/boiler-efficiency.htm⟩.2009.

[50] Albanese VM, Keleher AG. Intermittently applied coating of magnesium hydroxidetoboilertubestopreventslaganddepositbuildup,GooglePatents;1984.

[51] SavingsAF.MinimizeBoilerBlowdown;2001.

[52] DOE-IAC U. Industrial Assessment Center (IAC) Database. Washington, DC, USA: Department of Energy; 2006.

[53] HarimiM,etal.Numericalstudyofheatlossfromboilerusingdifferentratiosof fibre-to-shellfrompalmoilwastes.JSciIndRes2008;67(6):440–4.

[54] KrishnanunniS.etal., Evaluation of HeatLossesinFireTubeBoiler;2012.

[55] Handbook CEE. Council of Industrial Boiler Owners (CIBO). 6035 Burke CentreParkway,Suite360Burke,VA.22015.edited by RonaldA.Zetiz.

[56] Saidur R, Ahamed J, Masjuki H. Energy, exergy and economic analysis of industrial boilers. Energy Policy 2010;38(5):2188–97.

[57] Havlena Vr, Findejs J. Application of model predictive control to advanced combustion control. Control Eng Pract 2005;13(6):671–80.

[58] Lee C-L, Jou C-JG. Saving fuel consumption and reducing pollution emissions for industrial furnace. Fuel Process Technol 2011;92(12):2335–40.

[59] Saidur R, Hasanuzzaman M. Energy and environmental analysis of electricalmotorinindustrialboilers.inEnergyandEnvironment.ICEE2009.In: Proceedingsofthe3rdInternationalConferenceon.2009.IEEE;2009.

[60] ⟨https://www.aps.com/main/services/business/WaysToSave/BusWaystoSave_16⟩. Ways to Save on Motor Energy Costs, 2008. 2008.

[61] Qureshi T, Tassou S. Variable-speed capacity control in refrigeration systems. Appl Therm Eng 1996;16(2):103–13.

[62] Energy Efficiency and Renewable Energy, U.S.D.o.E. Energy Tips: STEAM, Upgrade Boilers with Energy-Efficient Burners.2012[cited201426.11.2014];Available from: ⟨http://www.energy.gov/sites/prod/files/2014/05/f16/steam24_burners.pdf⟩.

[63] Hanson RC, Hanson LC. Feed forward combustion control system, Google Patents; 1985.

[64] GilmanG, GilmanJ. Boiler control systems engineering:Isa;2010.

[65] Agency EP. Guide to Industrial Assessments for Pollution and Energy Efficiency.EPA/625/R-99/003; 2001.

[66] Milewski J, Discepoli G, Desideri U. Modeling the performance of MCFC forvarious fuel and oxidant compositions. Int J Hydrog Energy2014;39(22):11713–21.

[67] Carpenter K, Kissock K, D'Antonio M. Common excess air trends in industrial boilers with single-point positioning control and strategies to optimize efficiency.inACEEEsummerstudyonenergyefficiencyinindustry;2007.

[68] ToolBoxTE.CombustionEfficiencyandExcessAir28/11/09;Available from:⟨http://www.engineeringtoolbox.com/boiler-combustion-efficiency-d_271.html⟩;2014.

[69] MilesTR,etal.Boilerdepositsfromfiringbiomassfuels.Biomass-Bioenergy1996;10(2–3):125–38.

[70] Nussbaumer T. Combustion and Co-combustion of biomass: Fundamentals, technologies, and primary measures for emission reduction†. Energy Fuels2003;17(6):1510–21.

[71] Lou C, Zhou H-C. Deduction of the two-dimensional distribution of temperature in a cross section of a boiler furnace from images of flame radiation. Combust Flame 2005;143(1–2):97–105.

[72] Zhou H-C, et al. Experimental investigations on visualization of three-dimensionaltemperaturedistributionsinalarge-scalepulverized-coal-firedboiler furnace. Proc Combust Inst 2005;30(1):1699–706.

[73] Li Z, et al. Improving the combustion performance of a660MWe down-fired utility boiler by adopting high efficiency combustion technologies. in Power and Energy Engineering Conference(APPEEC),2011Asia-Pacific.2011.IEEE.

[74] Cleaver Brooks. BOILER EFFICIENCY GUIDE [cited 2014 29.11.2014]; Available from: ⟨http://www.cleaver-brooks.com/reference-center/insights/boiler-efficiency-guide.aspx⟩; 2014.

[75] Johnson I, et al. Waste heat recovery: technology and opportunities in US industry. US Department of Energy, Office of Energy Efficiency and Renewable Energy, Industrial Technologies Program; 2008.