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Boilers Performance Evaluation of Zuara Desalination Plant

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ABSTRACT

Water is the basis of daily life and industrial development for all communities. Water desalination plants emerged as one of the most important alternatives to overcome the shortage of water resources especially in desertified countries like Libya. Boilers are the main part in thermal desalination plants which depends on steam as the working fluid to heat and evaporate the seawater. with a capacity of 80 tons/hr of superheated steam at 220℃ and 15bar. Due to operating conditions, there was a decrease in steam boilers productivity and low efficiency. Heavy black smoke in chimneys was also detected. This work investigates the performance of the above mentioned boilers to determine the actual causes of these negative results by comparing the design values with different operating readings data. The results show a decrease in the efficiency of the boilers for low loading rates, which is affected by the air/fuel ratio. The deviation of this ratio from the design values leads to low efficiency and the emergence of heavy smoke in the chimneys, which causes deposits on the boiler pipes reducing the effectiveness of heat exchanger and therefore the thermal efficiency. The study also shows that the long operation suspension of the boilers in the first years of its life, due to the lack of discharge network and electricity cutoffs resulted in bad effect on the pipes conditions. The last led to the pipes deterioration resulting in water leaks and thus low boilers evaporation rates.

Keywords: desalination; boiler; thermal efficiency; air/fuel ratio.

1. Introduction

Water is the source of life used on in houses, agriculture, industry…etc. The lack and contamination of existing potable water resources led to desalination emergence as an important alternative resource to make up the shortage of demand especially in the countries that suffer from dryness. In general, there are two main types of seawater desalination technology one is the thermal or phase change processes and the other is membrane or processes without phase change. Desalination thermal processes are mostly found in countries, where fuel is quite cheap. Steam is used as the working fluid in desalination thermal type. The steam can be supplied by exhausting or bleeding steam turbines, or directly from boilers. The last one has an advantage of offering the steam with the required quality and quantity.

Performance evaluation is one of the essential requirements for the conservation of energy and optimization of operating parameters of boilers. There are many studies and researches in the field of performance evaluation of boilers contributed lifting of efficient production in many factories, desalination and power plants. As per the study carried out by Pachaiyappan[1] entitled improving the boiler efficiency by optimizing the combustion air, in which the performance of the air preheater has been studied on the basis of the combustion air passing through it. The author concluded that the correct optimization of the combustion air can increase the boiler efficiency by 2-3%, and also ensures less fuel consumption. By reducing the air preheater leakage, the auxiliary power consumption is also reduced. Thus the fuel is saved which leads to a considerable amount of profit.

Bora1 and Nakkeeran[2] presented an article about the performance analysis from the efficiency estimation of coal fired boiler. This paper puts forward an effective methodology for the efficiency estimation of a coal fired boiler, in comparison with its design value and enlists some of the factors that affect the performance of a boiler and it will help to increase overall boiler efficiency and as a result, annual monetary savings of the thermal power plant.

Improvement of boiler's efficiency using heat recovery and automatic combustion control system was studied by Suntivarakorna and Treedetb [3]. This research was conducted to improve the efficiency of a fire tube boiler with a fixed gate and screw conveyor for feeding fuel, the experimental result indicated that using heat recovery and fuel drying reduces by 3%wt of fuel moisture content and boiler efficiency increases by 0.41%.

As per the study carried out by Baladhiya and Doshi [4], performance evaluation and optimization of steam generating systems. The automatic controls used in modern boilers have improved the efficiency of the boiler by optimizing operating parameters required for efficient combustion process and to achieve safety in operation of fuels. Operation of boiler under optimum conditions not only helps in reducing the cost of steam generation but also helps in reducing the air pollution.

Lahijani and Supeni [5] presented a work about the evaluation of the effect of economizer on efficiency of the fire tube steam boiler. The results show the effect of using an economizer increases the feed water temperature and improves the efficiency of fire tube steam boiler.

Zuara multi effect type (MED) desalination plant is a thermal type. The first stage of the plant contains three water pipes for the boilers, with a capacity of 80 tons/hr. The produced steam has a temperature of 220ºC and pressure of 15 bar. The plant was inaugurated in the beginning of 2006.At this stage the boilers thermal efficiency have exceeded 92%. Over time, due to the operating conditions of the plant, there was a decrease in steam boiler productivity and low efficiency.

The objective of this study is to compare the operation real reading data of boilers in the plant with the design values confirmed by the performance tests and detect the reasons behind the low efficiency and productivity of the plant.

2. Materials And Methods

Two types of boilers data were collected. The design data was taken from plant documents and the actual operating data (real time data) was taken from the control room of Zuara desalination plant. It is available as daily and shifts reports from the first unit start up until the last boiler shutdown. The operating reading data selected along the boilers operating life cycle with different load rates. Table (1) presents sample of design and readings data for the boiler unit1[6].

Table 1:Design and real data for different annual operating periods of boiler unit 1.

Item	Unit	Design value	Annual real data				
			2007	**2009**	**2011**	**2013**	**2014**
Feed water flow rate	t/h	80.000	68.049	72.211	75.684	72.738	70.708
Feed water temperature	°C	115.00	112.96	113.07	113.08	113.07	112.96
F.W temp. after economizer	°C	165.00	165.33	174.38	176.64	173.39	149.94
Fuel mass flow rate	kg/h	4485.2	4221.8	4595.4	4732.0	4607.5	4411.8
Boiler steam product	t/h	80.000	67.598	71.040	74.342	70.003	58.035
Steam pressure	Bar	16.00	15.00	15.03	15.00	15.08	14.79
Steam temperature	°C	233.00	219.51	219.92	222.25	221.88	220.79
Air mass flow rate	t/h	76.845	72.896	69.379	81.565	84.315	81.677
Eco. Inlet gases temp.	°C	355.00	340.92	380.64	413.54	404.9	389.67
Stack temperature	°C	150.00	159.11	177.68	185.09	194.88	169.48
Boiler operating hours/year	hr	---	2093	2857	6103	6506	4502

3. Theory and Calculation

The performance evaluation parameters of boiler, like efficiency and evaporation ratio are reduced with time due to poor combustion, as well as the heat transfer surface fouling and poor operating and maintenance conditions. Even for new boilers, some reasons such as fuel and water quality can result in poor boiler performance. Boiler efficiency tests are helpful in finding the deviation of boiler efficiency from the best or design efficiency and target problem area for corrective action. Several indicators must be identified that affect the boiler efficiency and also help to determine the reasons behind the deviation.

3.1 Boiler Efficiency η_B:

The efficiency of any equipment is generally defined as the percentage of net energy obtained from the equipment to the total energy given to the machine, regardless of the type of the energy, mechanical, thermal or chemical. There are two methods to calculate the boiler efficiency, for direct and indirect methods. The direct method which is used in this study is easy to apply and does not require many complicated devices. The method is summarized as follows [7]:

$$\eta_{Boiler} = \frac{\dot{m}_s(h_e - h_i)}{\dot{m}_f * HV} \quad (1)$$

3.2 Boiler Evaporation Rate(B.E.R):

It is the ratio between the steam produced from the boiler and the fuel consumption, i.e. the number of kilograms of steam obtained when burning one kilogram of fuel, which expresses the performance of the boiler without paying attention to the type and quality of the steam produced or type of fuel consumed [8].

$$B.E.R = \frac{\dot{m}_s}{\dot{m}_f} \qquad (2)$$

3.3 Air Fuel Ratio (A/F):

The normal way to control excess air volume (Air/Fuel ratio) is by measuring the content of the exhaust gas from the oxygen and adjusting the ratio between fuel and air to achieve the maximum air level as low as possible, while maintaining complete combustion [8].

$$A/_F = \frac{\dot{m}_a}{\dot{m}_f} \qquad (3)$$

3.4 Economizer Effectiveness ε :

The economizer is a heat exchanger used to heat feed water before entering the boiler. It can also be used to heat the combustion air. The effectiveness of the economizer is defined as the ratio of the actual heat transfer rate to the maximum possible heat transfer rate. It can be expressed as: [8]

$$\varepsilon_{Economizer} = \frac{q}{q_{max}} \qquad (4)$$

$$q = \dot{m}_w Cp_w (T_{co} - T_{ci}) \qquad (5)$$

$$q_{max} = C_{min}(T_{hi} - T_{ci}) \qquad (6)$$

4 Results And Discussion

The required results were obtained by substituting the boiler operational data in the previous mathematical relationships. Some important assumptions should be taken in consideration to facilitate the access the results.

- The heating value of the heavy fuel used in the plant is constant and equal to 44084kJ/kg.K[6].
- The thermal heat capacity of feed water is constant and equal to 4.186kJ/kg.K[8]
- The thermal heat capacity of gases combustion is constant and equal to 1.17kJ/kg.K [6]

Tables (2),(3)and (4) show the most important results obtained for the three boilers.

Table 2:Performance indicators for boiler unit 1.

Performance indicators	Design value	Results from real data				
		2007	2009	2011	2013	2014
Boiler Load %	100.00	84.50	88.80	92.93	87.50	72.54
Boiler thermal efficiency %	92.32	86.20	83.21	84.57	81.78	70.96
Boiler evaporation rate	17.00	16.01	15.46	15.71	15.19	13.15
Air fuel ratio (A/F)	16.75	17.27	15.10	17.24	18.30	18.51
Economizer effectiveness%	85.42	79.76	75.85	76.03	71.97	79.57

Table 3: Performance indicators for boiler unit 2.

Performance indicators	Design value	Results from real data				
		2007	2009	2011	2013	2014
Boiler Load %	100.00	74.79	90.75	94.04	82.79	79.50
Boiler thermal efficiency %	92.32	88.04	85.41	83.90	81.42	74.93
Boiler evaporation rate	17.00	16.35	15.87	15.59	15.13	13.89
Air fuel ratio (A/F)	16.75	16.95	15.32	16.27	19.06	16.98
Economizer effectiveness%	85.42	85.55	71.58	70.65	74.38	77.03

Table 4: Performance indicators for boiler unit 3.

Performance indicators	Design value	Results from real data				
		2007	2009	2011	2013	2014
Boiler Load %	100.00	77.11	89.65	87.39	88.56	80.23
Boiler thermal efficiency %	92.32	84.86	82.46	81.56	81.13	75.69
Boiler evaporation rate	17.00	15.76	15.32	15.15	15.07	14.03
Air fuel ratio (A/F)	16.75	16.16	16.92	16.22	16.86	17.52
Economizer effectiveness%	85.42	84.79	76.81	72.64	74.71	72.90

Tables (2),(3) and (4)present the performance indicators for boilers units 1,2 and 3 respectively. It can be seen that the thermal efficiency of the boilers is directly proportional to the boiler load rate. The evaporation rates are also increased by increasing the boilers loads. Figure(1) shows the affect of the loads on the boilers thermal efficiency. It is also clear that the plant in its first years of operation has not been operating with high productivity. This is also evident from the total number of boilers operating hours due to the absence of an integrated water network linking the desalination plant to the consumption areas. During this period only one boiler was operated. Even though the other boilers were periodically operated this act resulted in the deterioration of their state.

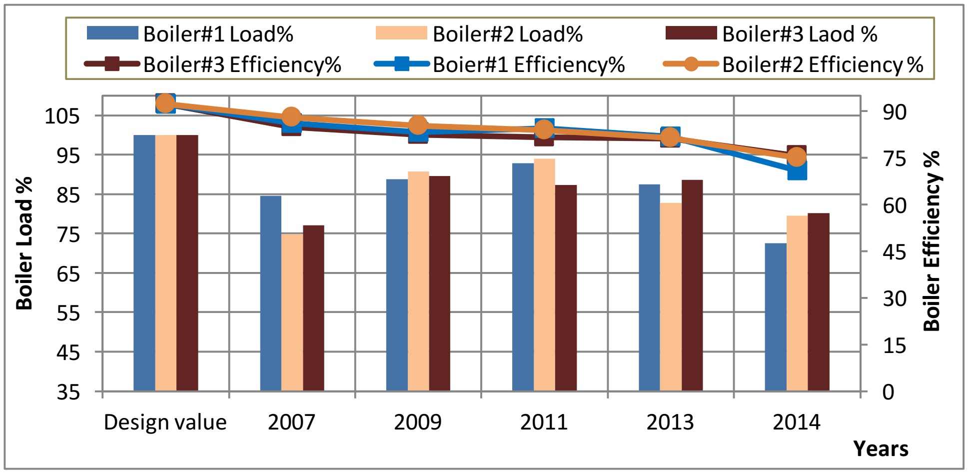

Figure1:Effect of boiler loads on boilers thermal efficiencies

The previous tables also show that the air/fuel ratio is unstable and variable in a random manner and certainly affects combustion rates. The deviation of this ratio from the design values leads to low efficiency and the emergence of heavy smoke in the chimneys,. which causes deposits on the boiler pipes reducing the effectiveness of heat exchanger and the thermal efficiency especially in recent years of boilers age.

Figure (2) shows the air/fuel ratio and economizer effectiveness. The random change in the air/fuel ratio affects the combustion efficiency. The increase of air ensures complete combustion, but causes a loss of part of the thermal energy with the excess air in combustion gases. On the other hand, the lack of air quantity leads to incomplete combustion and therefore the emergence of thick black smoke in chimneys and increase the amount of this smoke, which causes the accumulation and crust on the pipes in the economizer and consequently, results in the low effectiveness of the economizer as well as a key factor in the corrosion of pipes and water leakage inside the boiler. The last was noticed through the water mass balance compared to the feed water and produced steam. This phenomenon was obs

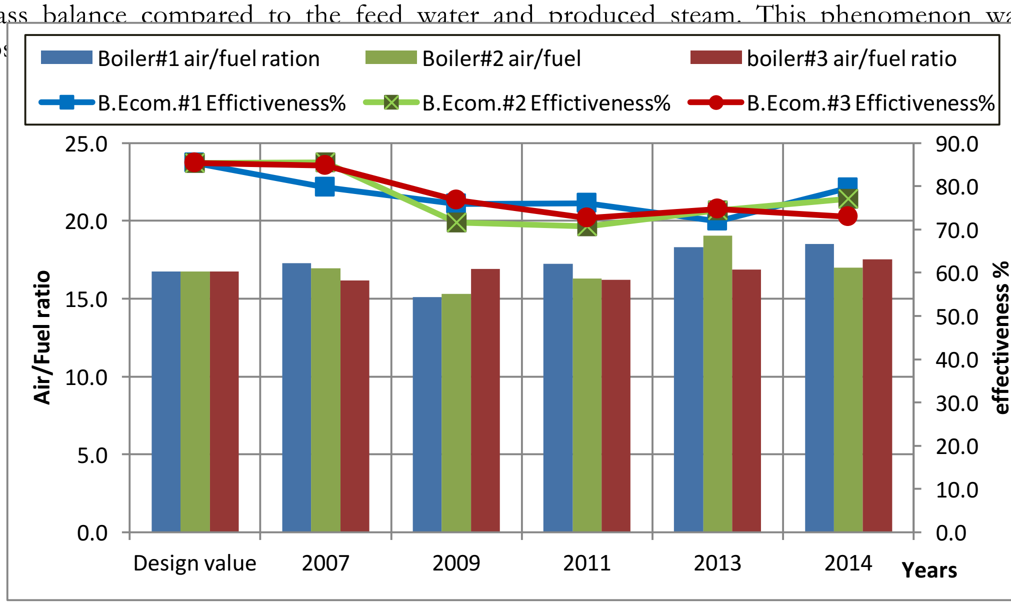

Figure 2: Air/fuel ratio and economizer effectiveness.

5 Conclusions

The boiler efficiency can be reduced by many factors. Zuara desalination boilers were exposed in the first years to long suspension period due to the absence of a network of transmission and distribution of water produced in the plant, as well as the sudden stops and frequent eruptions due to power outages in recent years. The previous problems have negative impact on the productivity of steam boilers and its efficiency and cause the corrosion for most of its parts and this lead to water leakage in the pipes. The poor mixing ratio of the air-to-fuel is a major cause of the black smoke of boilers, which due to its abundance and difficulty of disposal has affected the efficiency of the economizer and thus the performance of the boiler, So it is recommended to modify the combustion air rate of fuel in a correct ratio according to the design values as well as the use of the system of the boiler soot blower periodically and regularly according to manufactures company procedure.

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