EXERGY AND ECONOMIC ANALYSIS OF DUAL PRESSURE WASTE HEAT RECOVERY BOILER

[1]UMIT GUNES, [2]ASIM SINAN KARAKURT

Abstract- Waste heat recovery systems (WHRS), uses exhaust gas in the boiler, are very important in terms of increasing energy efficiency and reducing green gas emissions. Due to this reason, WHRS get more importance. Although dual pressure WHR boiler is more efficient than single pressure boiler, dual pressure boiler needs more heat transfer surface are. When the stage of boiler increases, the size of boiler also increases so it makes dual pressure more expensive. Engine load, exhaust gas temperature and fuel types, effect exhaust gas energy level, are the efficiency parameters for WHRS. In this study two-stroke Diesel engine performance is analyzed in terms of thermal efficiency, engine load, specific fuel oil consumption (SFOC), exergy efficiency and exegetic performance coefficient (EPC). It is shown that which boiler type is suitable due to the working condition in term of technical size and economic parameters.

Keywords- Waste Heat Recovery System (WHRS); Single Pressure Boiler; Dual Pressure Boiler; Two-Stroke Diesel Engine; Energetic Efficiency; Exegetic Performance Coefficient.

I. INTRODUCTİON

Recently, waste heat energy recovery methods are gained more importance day by day, due to the importance given to energy efficiency, A huge amount (25%) of the total energy is discharged by exhaust gas in a 2 stroke diesel engine which produces 49.3% shaft power, as seen in Figure 1[1].

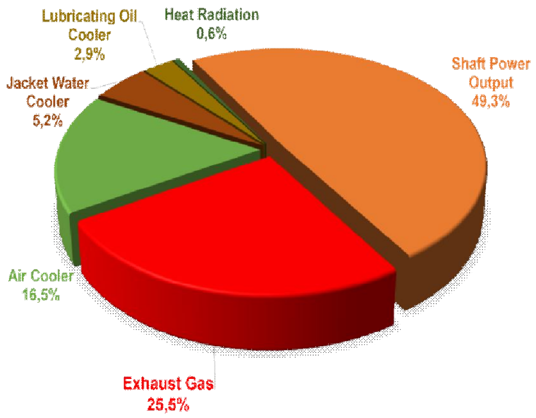

Figure. 1. Net power and heat loses in a ship [1]

Waste heat boilers are one of the most used waste heat recovery methods that classified to intended use. Single-stage (single pressure) waste heat boilers are used for smaller systems and also dual-stage systems are used for higher capacity systems behalf of thermoeconomic advantageous. Efficiency of WHRS with dual pressure boiler is 20% higher than with single pressure boiler[2].

In and Lee [3] has investigated to optimum design parameters of HRSGs to maximize the efficiency of bottom cycle of the CCPP by minimizing the irreversibilities. In order to validate the proposed method, a single-stage HRSG system was chosen, and the optimum evaporation temperature was gained to maximum useful work at given conditions of water and gas temperatures at the inlets of the HRSG system. It is shown from the results that the optimum evaporation temperature obtained and NTU effects on the research parameters which is important for determining the optimum conditions when the investment cost is considered with the operating cost.

Butcher and Reddy [4] investigated the effects of various operating conditions on the performance of a WHR power generation system based on second law analysis. The results showed that first and second law efficiencies of the WHR power generation system depend on exhaust gas composition and with oxygen content in the gas, specific heat and pinch point.

Reddy et al. [5]studied the influence of gas specific heat, non-dimensional inlet gas temperature difference ratio (τ), heat exchanger unit sizes, on the entropy generation number of a WHRSG and the results showed the influence of different non-dimensional operating parameters on entropy generation number, which in turn will be useful to optimize the performance of the unit.

Guo et al. [6]have analyzed the effects of heat/exergy loss to the environment on a waste heat power generation system that based on the energy and exergy efficiencies and entropy generation to impress on how some operating parameters could affect the performance The resutlst showed that the optimal operation condition should be reached at the trade-off between the heat/exergy input and the heat-work conversion ability of the unit.

Franco and Giannini[7] roughed in a technique to obtain the main operating parameters and detailed design of the component concerning the geometric variables of the heat transfer sections for minimization of the pressure drop and overall dimensions of HRSG.

Naemi et al [8] have presented a new objective function including the exergy waste and the exergy destruction, which is defined in such a way to find the optimum pinch point, and non-dimensional operating parameters. The first and second law and econo analyses are investigated to achieve the optimum operating parameters and economic conditions of a dual pressure HRSG.

Ahmadi and Dincer[9] have analyzed a combined cycle power plant (CCPP) with a supplementary firing system that is based on the first and second law of thermodynamic. The optimal design of operating parameters of the plant is made by pointed out an objective function and applying a generic algorithm (GA) type optimization method. In order to optimally find the design parameters, a thermo-economic method is proposed. In addition to this, the effects of variable power demand and fuel cost are studied for three different power output.

II. WASTE HEAT RECOVERY SYSTEM

The most important component for waste heat recovery is boiler. The heat which is rejected with the exhaust gas use for heat transfer to water of WHRS. After heating and boiling the fluid is send to turbine.

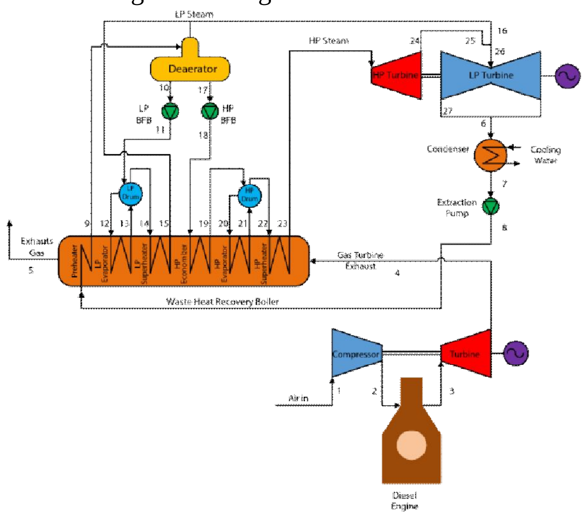

Figure 1. Waste Heat Recovery System

III. DUAL PRESSURE WASTE HEAT RECOVERY BOILER

The working principle of dual pressure waste heat recovery boiler is different than single pressure. Although there is one pinch point and one system pressure (figure 1), dual pressure boiler has 2 pinch point and two system pressure; Low Pressure, High Pressure (figure 2). When number of pinch poit increases, it means more heat transfer so more heat recovery. WHRS with dual pressure has 20% higher efficiency than with single pressure boiler [2].

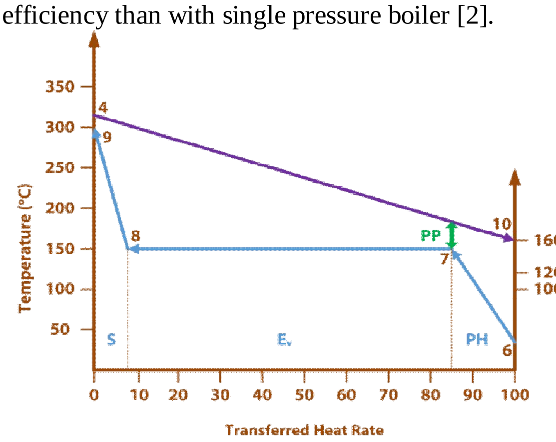

Figure 2. Single Pressure Waste Heat Recovery Boiler

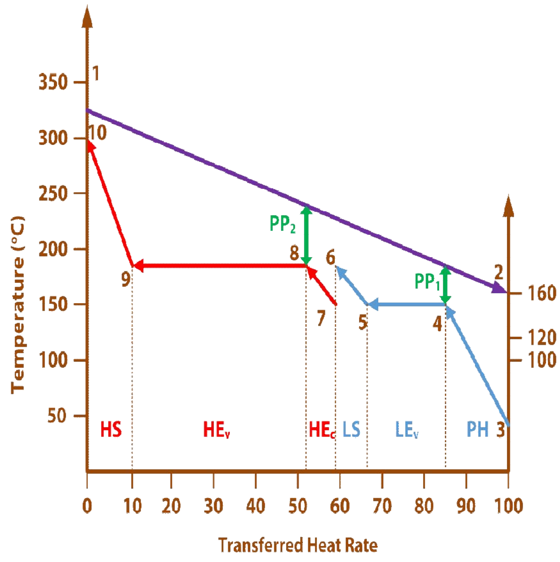

Figure 3.Dual Pressure Waste Heat Recovery Boiler

IV. THERMODYNAMIC SIMULATION

3.1 Energy Analysis

General energy equation is defined below for steady state open system:

$$\dot{Q}_i + \dot{W}_i + \sum_i \dot{m}\left(h + \frac{V^2}{2} + gz\right) = \dot{Q}_o + \dot{W}_o + \sum_o \dot{m}\left(h + \frac{V^2}{2} + gz\right) \quad (1)$$

where $(\dot{m})$ is flow rate, $(\dot{Q})$ is heat transfer rates, $(\dot{W})$ is powers, (h) is enthalpies, $\left(\frac{V^2}{2}\right)$ is kinetical energy and $(g \cdot z)$ is potential energies. Subscript i shows inlet and subscript o shows outlet

3.2 Exergy Analysis

Exergy values of every state points in steady state open system are calculated by equation 2:

$$\dot{E}x_i^F = \dot{m}\left[(h_i - h_0) - T_0 (s_i - s_0)\right] \quad (2)$$

where $(\dot{E}x_i^F)$ is physical exergy, (s_i) is entropy and subscripts "0" is refer to ambient conditions.

$$\dot{E}x_{i,i} = \dot{E}x_{o,i} + \dot{E}xD_i \quad (3)$$

where $(\dot{E}x_i)$ indicates exergy and $(\dot{E}xD)$ indicatesexergy destruction in the processes.

General exergy destruction of control volume in a steady state is defined as equation 4:

$$\dot{E}xD_i = \sum \dot{Q}_i\left(1 - \frac{T_0}{T}\right) - \sum \dot{Q}_o\left(1 - \frac{T_0}{T}\right) + \sum(\dot{W}_i - \dot{W}_o) + \sum(\dot{E}x_i - \dot{E}x_o) \quad (4)$$

Exergy destruction rate of heat transfer process shows in equation 5:

$$\dot{E}xD_i = \sum \dot{Q}_i\left(1 - \frac{T_0}{T}\right) - \sum \dot{Q}_o\left(1 - \frac{T_0}{T}\right) + \sum(\dot{E}x_i - \dot{E}x_o) \quad (5)$$

For boiler, there is no heat transfer out. So the equation will be:

$$\dot{E}xD_i = \sum \dot{Q}_i\left(1 - \frac{T_0}{T}\right) + \sum(\dot{E}x_i - \dot{E}x_o) \quad (6)$$

V. RESULTS AND DISCUSSION

When get 15 ^{o}C pinch point for both pressure, the system pressure is calculated 4.75 bar for low pressure system and 13.68 bar for high pressure. If just single pressure is used, the pressure will be 5 bar. And it means than lower heat transfer ratio.

Exergy destruction shows in table 2. The most Exergy destruction occurs in LP evaporator and HP evaporator.

Table 1. The Property of the states

State	T_i (^{o}C)	P_i (bar)	h_i (kJ/kg)	s_i (kJ/kg.k)
0	30	1	125,8	0,4365
1	350	4	631,7	6,054
2	160	1,2	434,9	6,024
3	30	4,75	126,1	0,4364
4	150	4,75	632,3	1,842
5	150	4,75	2746	6,838
6	182	4,75	2818	7
7	150	13,68	632,9	1,841
8	194	13,68	825,5	2,274
9	194	13,68	2789	6,477
10	335	13,68	3117	7,094

Table 2. Exergetic Performance Coefficient (EPC_i), Exergetic efficiency (ε_i) and Exergy Destruction Ratio (y_i) of the Boiler Component

System Components	E_xD (kW)
Preheater	174,9
LP Evaporator	736,1
LP Superheater	25,32
HP Economiser	275,7
HP Evaporator	2814
HP Superheater	239,3
Total	

CONCLUSIONS

Dual pressure boiler have been analyzed with respect to energy and Exergy analysis. The results show that the highest Exergy destruction is obtained in LP and PH evaporator. All analyses is done in terms of 15 ^{o}C pinch point. In this study shows that the performance of elements of boiler. The study needs also size analysis.

REFERENCES

[1] M A N Diesel & Turbo, "Waste Heat Recovery System (WHRS) for Reduction of Fuel Consumption, Emissions and EEDI."

[2] D. A. Snow, Ed.,Plant Engineer's Reference Book, Second Edition, 2 edition. London; Boston: Butterworth-Heinemann, 2003.

[3] J. S. In and S. Y. Lee, "Optimization of heat recovery steam generator through exergy analysis for combined cycle gas turbine power plants," Int. J. Energy Res., vol. 32, no. 9, pp. 859–869, Jul. 2008.

[4] C. J. Butcher and B. V. Reddy, "Second law analysis of a waste heat recovery based power generation system," Int. J. Heat Mass Transf., vol. 50, no. 11–12, pp. 2355–2363, Jun. 2007.

[5] C. L. Zhang, E. J. Chen, and B. G. Wang, "Second Law Analysis of a Waste Heat Recovery Steam Generator with Variable Working Condition Flue Gas," Adv. Mater. Res., vol. 347–353, pp. 1070–1074, Oct. 2011.

[6] J. Guo, M. Xu, and L. Cheng, "Thermodynamic analysis of waste heat power generation system," Energy, vol. 35, no. 7, pp. 2824–2835, Jul. 2010.

[7] A. Franco and N. Giannini, "A general method for the optimum design of heat recovery steam generators," Energy, vol. 31, no. 15, pp. 3342–3361, Dec. 2006.

[8] S. Naemi, M. Saffar-Avval, S. Behboodi Kalhori, and Z. Mansoori, "Optimum design of dual pressure heat recovery steam generator using non-dimensional parameters based on thermodynamic and thermoeconomic approaches," Appl. Therm. Eng., vol. 52, no. 2, pp. 371–384, Apr. 2013.

[9] P. Ahmadi and İ. Dinçer, "Thermodynamic analysis and thermoeconomic optimization of a dual pressure combined cycle power plant with a supplementary firing unit," Energy Convers. Manag., vol. 52, no. 5, pp. 2296–2308, 2011.

★★★