Exergy Analysis of NEKA-IRAN Heat Recovery Steam Generator at Different Ambient Temperatures

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Abstract -The supplementary firing is one of the techniques which are used to increase the output power of the combined cycle power plants (CCPP). The low construction cost per generated power encourages designers to consider it in the new CCPP. In this paper exergy analyses of HRSG with and without supplementary firing are presented. They are based on the performance test data at different operating conditions. The objective of these analyses is to present the effects of supplementary firing on gross power output, combined cycle efficiency and the exergy loss in Heat Recovery Steam Generator (HRSG) devices at different ambient temperatures. The results show that the most effective components for the exergy losses are stack, LP-EV and LP-SH at different ambient temperature.
The effect of the supplementary firing on the exergy loss has been studied as well. The results reveal that although the supplementary firing increases the gross output power of the combined cycle power plant, however it increases the total exergy loss of HRSG and consequently decreases the total exergy and thermal efficiency.

Key Words: -supplementary firing, exergy, thermal efficiency, combined cycle power plant, heat recovery steam generation

1. Introduction

Combined cycle power plants are going to have the first rank among power generators in the world. Some predictions indicate that over than 50% of the new power plants in the USA will be CCPP installations [1]. Optimization of the heat recovery steam generator (HRSG) operating parameters are considered as one of the most interesting strategies to obtain an increase in the combined cycle plant performance. For example Casarosa and Franco have demonstrated in their studies the optimization of HRSGs by using two or more steam and water streams that exchange with the exhaust gas stream [3]. C. Casarosa, F. Donatini, A. Franco. in their studies have discussed some of the HRSG optimization methods [5].
A brief look at the recent studies shows that most of the researches are tried to increase the efficiency. However, in the real world, the power cost is different during a year or even during a day. Therefore, the financial supporters are interested in finding low cost methods to increase output power in the special period of time (i.e. peak time) although the efficiency may decrease as well. The supplementary firing is an available choice for these cases which is going to be used more in the new HRSG installation. Sue and Chuang [1] have studied the power output and efficiency enhancement methods proposed in the past years for some of the installed power plants in Taiwan. They include the compressor inlet air cooling, preheating the fuel gas, and supplemental firing of the HRSG, to increase the steam turbine power output. However, like other researchers they have not presented the results of supplemental firing effects separately.
The effects of supplement firing on the gross power output, combined cycle efficiency and exergy loss in HRSG have not been completely discussed by exergy analysis in the literatures. Therefore, this matter is studied in this paper from the exergy point of view for the CCPP operation at the base and partial loads.

2. Problem Formulation

2.1.NEKA Power Plant Description

NEKA CCPP is one of the Iran power plants which is located close to the Neka city beside the Caspian Sea. As it is shown in the Fig.1, this power plant has two gas turbines, two compressors, two HRSGs, two deaerators, one steam turbine and one surface condenser with once through cooling system which uses sea water as the cooling water media.

The Siemens V94.2 gas turbines of this combined cycle have been installed in 1982. The performance test result which is used during this project is given in the table 1. For steam cycle the process data of gas and steam flow at three main operating cases at both fired and unfired modes are given in tables 2-3. These tables are used as input data in next section.

2.2.Analysis Method

Exergy analysis is a well-known thermodynamic method which is widely used in the evaluation and optimization of the thermodynamic and process systems. One of the best exergy definitions is given by Dincer and Cengel [6] which defines exergy as "the maximum amount of work which can be produced by a system or a flow of matter or energy as it comes to equilibrium with a reference environment". This means that exergy analysis is a valuable tool in practical studies. Scientists have used this matter to define the exergy efficiency.

$$\eta_{Ex} = \frac{\dot{E}_{xout}}{\dot{E}_{xin}} \quad (1)$$

For $\dot{E}_x = \dot{m} e_x$

By considering the first and second laws, one can write:

$$\dot{E}_W = \dot{E}_Q + \sum_{in} \dot{m} e_x - \sum_{out} \dot{m} e_x - T_0 \dot{S}_{gen} \quad (2)$$

$$\dot{E}_Q = \left(1 - \frac{T_0}{T_j}\right) \dot{Q}_j \quad (3)$$

$$\dot{E}_W = \dot{W} \quad (4)$$

The following expressions can be written for the exergy contained in a system:

$$e_x = u + P_0 v - T_0 s - \sum_i \mu_{i0} \quad (5)$$

The subscript "0" denotes conditions of the reference environment and we can write it as follow:

$$e_x = (u - u_{eq}) + P_0 (v - v_{eq}) - T_0 (s - s_{eq}) + \sum_i \mu_{i0} \quad (6)$$

The quantities on the right hand side can easily be determined. Therefore, it is thus an easy task to determine the exergy content of a given system in a given environment. For a substance which has an exergy content deriving only from its concentration the following relation holds.

$$e_x = RT_0 \ln(c / c_0) \quad (7)$$

Where c is the concentration of the substance in the material considered, and c_0 is the concentration of the substance in the environment.

The chemically reacting materials receive an additional exergy contribution from the change in the chemical potential. Hence we can write:

$$e_x = (\mu - \mu_0) + RT_0 \ln(c / c_0) \quad (8)$$

Where μ_0 is chemical potential for the material in its reference state.

3. Problem Solution

3.1. The Effects of Ambient Temperature on the HRSG Lost Exergy

In this study the fired and unfired cases are compared at different ambient temperature while both gas turbines are working at base load (100% load). In the combined cycle power plants, ambient temperature influences the gross power output and efficiency not only by affecting gas turbines power output but also by affecting on the gas turbines exhaust gas conditions and consequently affecting the HRSG inlet flue gas conditions. In Figs. 2-4, the exergy losses of HRSG versus ambient temperature for both fired and unfired cases at the yearly minimum average of 13.5^0 C, yearly average of 17.3^0 C, yearly maximum average of 20.9^0 C and absolute maximum 39^0 C ambient temperature conditions have been shown. Fig.2 reveals that the exergy losses for the fired cases are more than unfired cases. It is clear that for the fired case, the temperature of flue gases inside HRSG increase while the temperature of water inside the tubes is constant. Therefore, it causes the increase of temperature difference during heat transfer and consequently increases the exergy loss. Also this figure shows that for the both fired and unfired cases the exergy losses are minimum at 17.3^0C due to the fact that HRSG has been designed for this temperature (design temperature) and any ambient temperature variation from design point, either increasing or decreasing, is not favorable for the HRSG performance.

Now, it is better to study each component of HRSG separately. Figs 3-4 show the comparison between HRSG components' exergy losses for unfired and fired cases at the above mentioned ambient temperatures. In these Figs. the components are arranged according to their installation position along the HRSG. It is necessary to mention that in these figures and the next ones, HP-SH losses refers to total losses of 1st, 2nd and 3rd superheaters.

According to Fig.3, for the unfired case, stack is the most irreversible part and it has the largest amount of losses. The stack has actually three irreversible processes. The first one is the mixing between exhaust gases and air, the second one is the pressure reducing, and the third one is the heat transfer from hot exhaust gases to ambient air during mixing process. It is obvious from the figures that if the ambient air temperature increases, the stack exergy loss will decrease. One reason for this decrease can be that the temperature differences during heat transfer in hot ambient air decreases. After stack, the heat transfer in HP-EV has more exergy loss than the other components. Both CPH and HP-SH has almost the same exergy loss and have the third rank after HP-EV. Also it is clear that except stack, all other components have minimum exergy losses at the yearly average ambient temperature.

Fig.4 shows how the supplementary firing increases the HRSG exergy losses. This figure reveals that exergy losses for most of the devices increase in firing mode. It is especially more intensified for LP-EV and LP-SH than the other components. Also, Fig.3 shows that stack, HP-EV and HP–SP (except at ambient temperature) are the most irreversible parts respectively. However, in this case the LP-SH has the forth rank instead of HP-EV in unfired case. In yearly average ambient temperature, the large decrease in HP-SH exergy loss minimizes exergy loss of HRSG (Fig.2) despite the increase in exergy loss in other components.

3.2. The Effects of the Supplementary Firing on the Combined Cycle Performance

As it has been discussed, it seems that supplementary firing increases the exergy losses in HRSG. However, on the other hand, the major goal of supplementary firing is to increase the combined cycle power plant output. In order to evaluate these disadvantage and advantage, the total efficiency of the combined cycle is to be calculated. In equation (1) $\dot{E}_{xout}$ is gross power output which are 425.15 MW and 395.92 MW for fired and unfired cases respectively. For this case, based on the gas fuel flow rate, $\dot{E}_{xin}$ is estimated as 953.88 MW and 859.76 MW for the fired and unfired cases respectively. By dividing these values one may calculate the exergy efficiency as $\eta_{Exfired} = 44\%$ and $\eta_{Exunfired} = 45.5\%$. Also, it is possible to estimate the thermal efficiency using the enthalpy of the fuel gas instead of the chemical exergy. It can be shown that the total thermal efficiency of the CCPP are $\eta_{thfired} = 46\%$ and $\eta_{thunfired} = 47\%$. These values show that although the supplementary firing increases the gross power output by 29.23 MW. However, it decreases the total efficiency by 1%.

4. Conclusions

One option to increase the gross output power of the combined cycle power plants is supplementary firing that affects directly the HRSG performance. Our exergy analysis reveals that supplementary firing increases some components exergy losses very much, while they are working at part load. These increases can be noted in the total HRSG exergy loss. Hence, the LP-EV and LP-SH optimization at different ambient temperatures is considered to be useful methods in optimization of HRSG in all working conditions.

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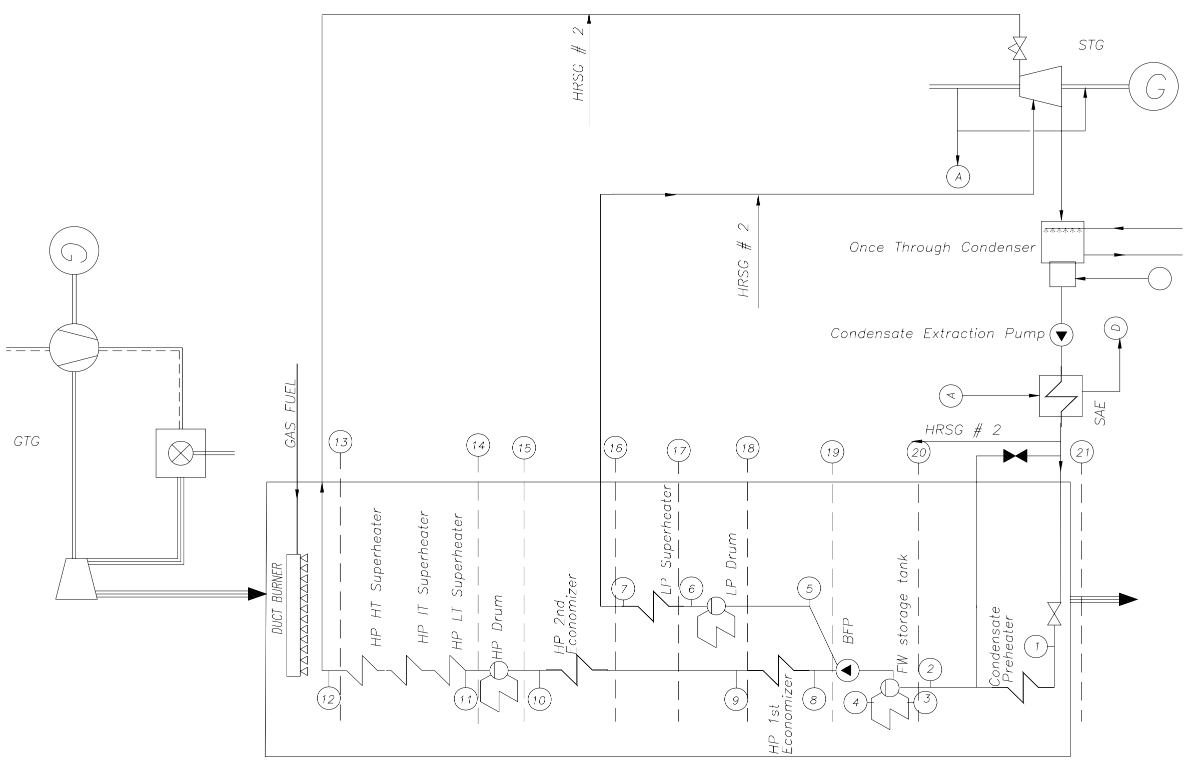

Fig. 1 Schematic of the process flow diagram for the Neka CCPP

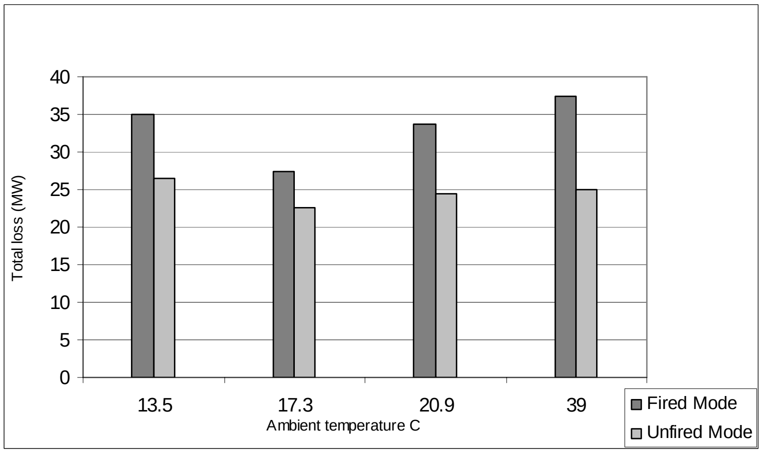

Fig. 2 The comparison of total exergy losses versus ambient temperature for the fired & unfired cases

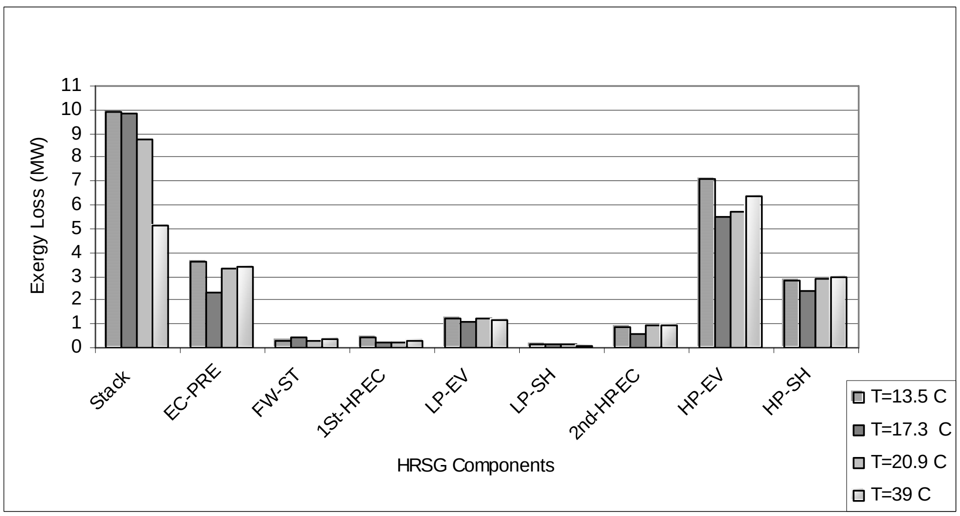

Fig.3 The exergy losses for the HRSG components for the different ambient tempratures for the unfired case

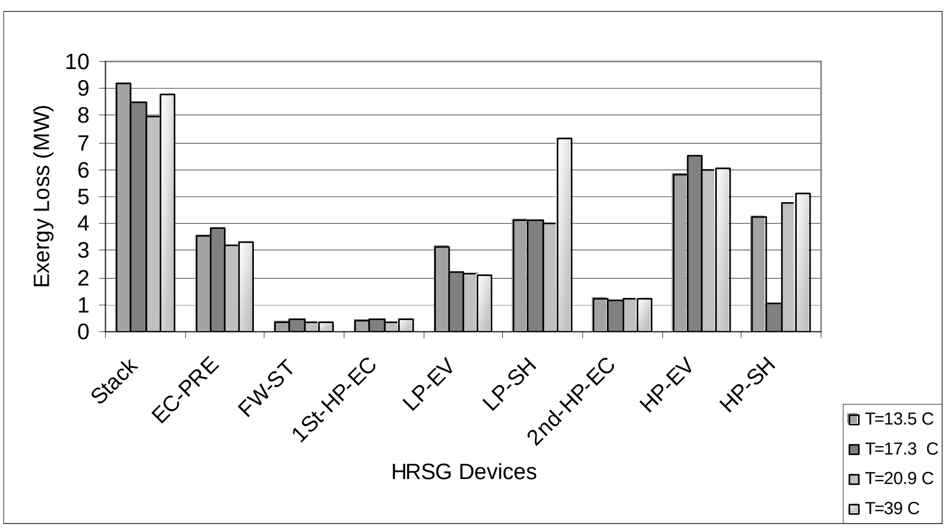

Fig.4 The exergy losses for the HRSG components for the different ambient tempratures for the fired case

Poin Description	P bar	$T(K^0)$	$\dot{m}(kg/s)$	$e\,(kj/kg)$
Compresor Inlet	$e\,(kj/kg)$	293.15	491.55	-0.51
Compressor outlet	10.1	594.14	491.55	269.5
Turbine inlet	10.1	1244.15	500	846
Turbine Outlet	$e\,(kj/kg)$	773.15	500	220

Table 1: Thermodynamic properties of air and exhaust gases for gas turbine.

	Fired case 100% Load Ta=17.3						**Unfired case 100% Load Ta=17.3**					
Point	m	P bar	T C	h kJ/kg	S kJ/kg	e	m	P bar	T C	h kJ/kg	S kJ/kg	e
1	274012	11.28	44.1	185.6	0.618	7.23	231022	15.28	44.1	185.9	0.616	7.27
2	274012	10.79	126.67	532.7	1.598	67.19	231022	14.91	141.62	596.8	1.57	138.58
3	13597.6	4.91	151.2	637.4	1.854	96.88	11195.6	6.99	164.91	696.9	1.8	172.2
4	13597.6	4.91	151.2	2746.8	6.825	749.78	11195.6	6.99	164.91	2761.9	6.703	799.72
5	32542.1	10.49	151.12	637.4	1.864	96.88	35873.1	10.59	164.87	696.9	1.922	135.55
6	32542.1	10.49	181.99	2777.9	6.566	856.77	35873.1	10.59	182.41	2778.3	6.562	857.43
7	32542	10	236.55	2912.7	6.868	903.08	35873.2	10.1	2920.6	2920.6	6.876	907.73
8	237310	110.46	149.67	637.4	1.843	104.14	195149	119.32	163.41	696.9	1.98	123.85
9	237310	109.97	180.45	770	2.145	147.86	195149	118.93	190.88	816.4	2.243	166.96
10	237310	108.27	299.62	1340.3	3.24	401.28	195149	117.78	292.02	1297.5	3.162	381.14
11	237310	98.97	310.2	2729.5	5.626	1083.79	195149	79.73	294.73	2760.3	5.76	1074.42
12	241471	96	523	3437.1	6.696	1477.88	195149	77.09	500	3361.7	6.693	1402.45

Table 2:Water and steam thermodynamic properties for the fired and unfired cases.

	Fired case 100% Load Ta=17.3						**Unfired case 100% Load Ta=17.3**					
Point	$\dot{m}$ kg/hr	T C	h kJ/kg	S kJ/kg	Cp J/kg-K	e	$\dot{m}$ kg/hr	T C	h kJ/kg	S kJ/kg	Cp J/kg-K	e
13	1802881	552.57	723.048	1.2007	1.1619	288.33	1800000	500	651.244	1.127	1.1502	247.9
14	1802881	478.28	637.457	1.092	1.1422	234.31	1800000	442.11	585.1129	1.0381	1.1345	207.59
15	1802881	313.99	453.441	0.816	1.0983	130.46	1800000	298.35	424.7922	0.788	1.0963	119.91
16	1802881	244.85	378.106	0.6795	1.0812	94.77	1800000	250.06	372.1409	0.6917	1.0845	95.23
17	1802881	242.58	375.653	0.6748	1.08	93.68	1800000	247.42	369.2787	0.6863	1.0838	93.94
18	1802881	206.52	336.833	0.5967	1.0725	77.55	1800000	208.6	327.3783	0.6026	1.075	76.35
19	1802881	190.08	319.11	0.5593	1.068	70.78	1800000	196.4	314.27	0.5751	1.072	71.24
20	1802881	175.07	303.209	0.5242	1.0659	64.98	1800000	184.27	301.2874	0.547	1.0698	66.4
21	1802881	124.89	249.963	0.3983	1.0566	48.3	1800000	134.06	247.8188	0.4232	1.0602	48.89

Table 3. Flue gas thermodynamic properties for the fired and unfired cases