Journal of Engineering Research and Applied Science
Available at www.journaleras.com
Volume 3(2) December 2014, pp 242-251
ISSN 2147-3471 © 2014

Exergy and energy analysis of 850 MW natural gas combine cycle plant

E.Toklu[1], M.Sencan[2,a],M.Gur[1]

[1]Duzce University, Mechanical Engineering, Duzce, Turkey.
[2]Duzce University, Manufacturing Engineering, Duzce, Turkey.

Accepted 12 October 2014

Abstract

In the field of the combined cycle plant analysis, thermodynamic optimization of the heat recovery steam generator, the steam turbine and the condensate unit is to much more important to able to improve the efficiency of the section of the plant from gas turbine exhaust and to maximize the power generated in the vapor cycle. Power has become an essential requirement all over the world today. Many countries interests with alternative energy source and countries are trying in order to power generate form renewable energy source too also they makes an effort for more effective production of existing power plants. May be we cannot avoid the all energy loss exactly but each reformation will be provided many earn for the world and national economy. Aliveness for people is done studies in order to achieve them also aliveness is sensitive point for developed countries. So that in this study, natural gas which was used fossil based has been examined with in combine cycle plant. Exergy and energy analysis have been determined for each unit in the plant with stated value through the operating datas and the total exergy and losses have been defined in the plant.

Keywords: Exerg; energy; efficiency; natural gas; heat recovery boiler; global energy

1. Introduction

The combine cycle power plant (CCGT) is one of the most important systems of energy generate and the cogeneration (combined heat and power CHP) idea is to taken an important place for affect the efficiency whole plant. Resource and development policy of CHP system is improved due to rapidly decreasing of the stock belong to energy source and many studies have been prepared thermo dynamic optimization of the CCGT.

Energy efficiency isn’t the calculated thermodynamic optimization or cogeneration system only. Also it is the energy consumption per unit of GDP. So that Energy efficiency can improve energy security, spur economic growth and mitigate pollution, but current and planned effects fall well short of tapping its full economic potential. A number of major energy consuming countries (China, United States, the European Union and Japan) have adopted new energy efficiency measures over the last year. Progress towards their implementation is projected to contribute to a reduction in global energy intensity (Energy consumption per unit of GDP) of 1.8 % a year through to 2035 in the new policies scenario, a major improvement compared with only 0.5 % per year over the last decade. Nonetheless, a signification share of the economic potential of energy efficiency – four-fifths in the buildings sector and more than half in industry- remains untapped, mostly due to non-technical barriers [1]. Please see figure-1 for change in power generation until to 2035.

What is usable water case in the world in this case of sector? Power plant operation system needs to much more water source in order to progress, cooling, pressure, power. So energy is becoming an important resource. Global freshwater use for energy production in 2010 totaled 583 million cubic meters (bcm) or some 15 % of the world’s total water use [1]. These amounts are danger and much more for a natural source as result. We require to know that there is an end of all natural sources. Wind and solar PV can be a solution against to a low-carbon energy future without intensifying water demands significantly. The human have to provide the minimum consumption of the energy source and the minimum entropy production in order to solution of the problem increasing all over the world.

---

[a] Corresponding author;
Phone: +90-506-554-1364, Email : mustafasencan@hotmail.com.tr

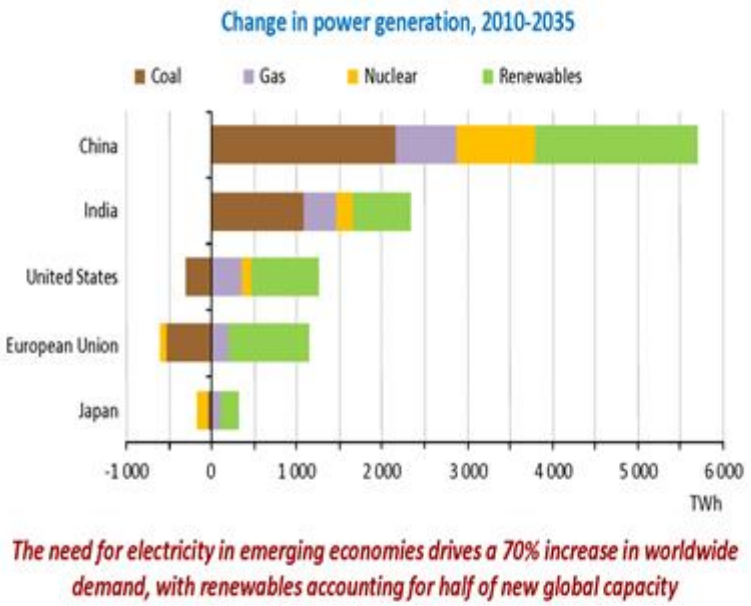

Figure 1. Change in Power Generation 2010-2035

2. Material and Methods

A combine cycle plant respectively and mainly is heat recovery steam generator (HRSG), steam generator (ST), air cold condenser (ACC) and the demi water system (DWS). This study will consist of five main systems (GT-HRSG-ST-ACC-DWS) and their sub-system. The GT is an interface between the gas reducing station and the HRSG. The GT is to generated approximately 300 Mw. energy and waste gas is used to superheat water vapor. The HRSG is an interface between the gas cycle and the extracted heat is used to generate steam. The ST is an interface between the HRSG and the ACC. The ST is to generated 300 Mw. energy approximately and waste steam is to used again in the ACC for recycling of plant. The ACC is an interface between the ST and the HRSG. The ACC is to used to cooling of waste water and for recycling. DWS is an interface between the ACC and the Demi Tank. DWS is produced the demineralized water in order to complete missing water requirement of plant. Please see Figure 2.1 for general chart of plant. To calculation of plant will be used actual operations data by help of competent staff and two kind ways will be followed as method within this study. Those are first and second law of thermodynamic. Traditionally, the basis for the study of energy conversation system has been the conversation of mass and the first law of thermodynamic. But efficiency based on the first law of thermodynamics cannot properly assess performance a HRSG when the final aim is production of work [2]. This notion is valid for each occurred from gas turbine (GT), of system efficiency.

The use of second law of thermodynamic offers a more appropriate approach carrying out the thermodynamic analysis with the minimization of the irreversibility. The entropy generation minimization was first applied in heat exchangers by bejan [3].

The second law of thermodynamics states that in general the total entropy of any system will not decrease other than by increasing the entropy of some other system. Hence, in a system isolated from its environment, the entropy of that system will tend not to decrease. It follows that heat will not flow from a colder body to a hotter body without the application of work (the imposition of order) to the colder body.

Secondly, it is impossible for any device operating on a cycle to produce network from a single temperature reservoir; the production of network requires flow of heat from a hotter reservoir to a colder reservoir, or a single expanding reservoir undergoing adiabatic cooling which performs adiabatic work. As a result, there is no possibility of a perpetual motion system. It follows that a reduction in the increase of entropy in a specified process, such as a chemical reaction, means that it is energetically more efficient.

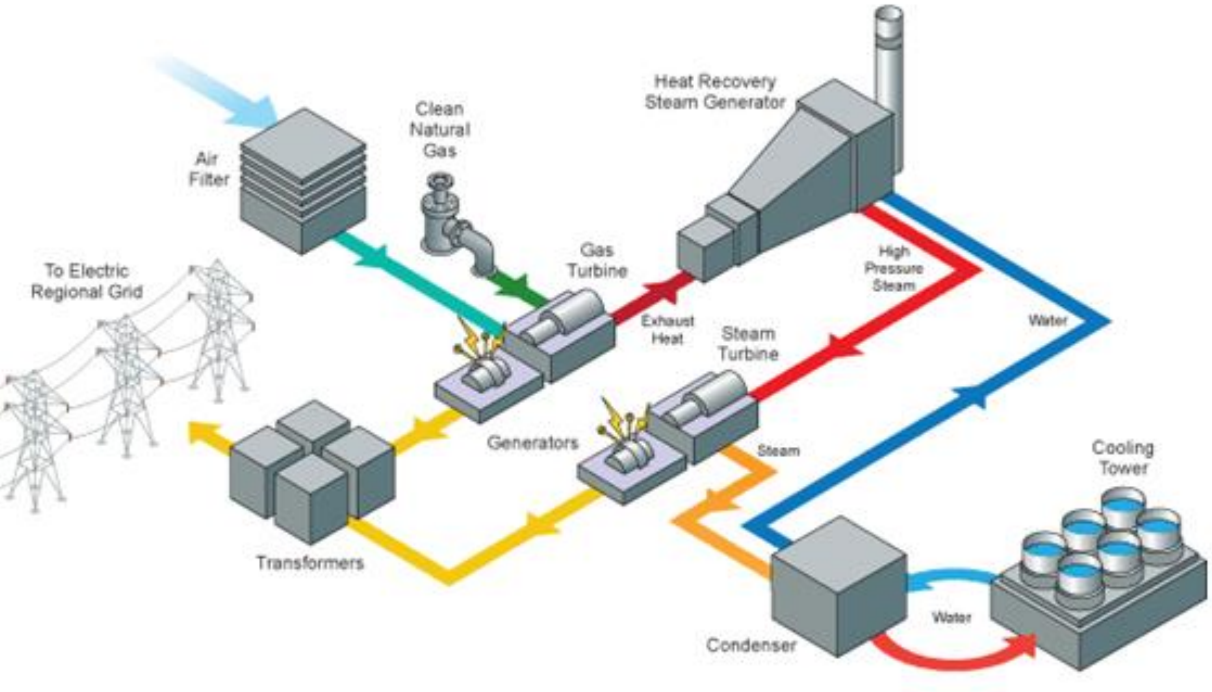

Figure 2. General chart of combine plant

It follows from the second law of thermodynamics that the entropy of a system that is not isolated may decrease. An air conditioner, for example, may cool the air in a room, thus reducing the entropy of the air of that system. The heat expelled from the room (the system), which the air conditioner transports and discharges to the outside air, will always make a bigger contribution to the entropy of the environment than will the decrease of the entropy of the air of that system. Thus, the total of entropy of the room plus the entropy of the environment increases, in agreement with the second law of thermodynamics.

In mechanics, the second law in conjunction with the fundamental thermodynamic relation places limits on a system's ability to do useful work.[4] The entropy change of a system at temperature (*T*) absorbing an infinitesimal amount of heat δq in a reversible way is given by δq/T. Statistical mechanics demonstrates that entropy is governed by probability, thus allowing for a decrease in disorder even in an isolated system. Although this is possible, such an event has a small probability of occurring, making it unlikely [5].

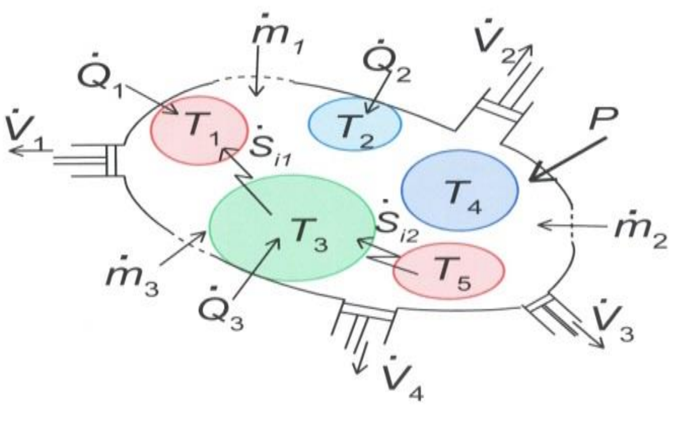

Figure 3. General representation of an inhomogeneous system that consists of a number of subsystems

The entropy of a system depends on its internal energy and the external parameters, such as the volume. In the thermodynamic limit this fact leads to an equation relating the change in the internal energy to changes in the entropy and the external parameters. This relation is known as the fundamental thermodynamic relation. If the volume is the only external parameter, this relation is:

$$dU = TdS - PdV \tag{2.1}$$

Since the internal energy is fixed when one specifies the entropy and the volume, this relation is valid even if the change from one state of thermal equilibrium to another with infinitesimally larger entropy and volume happens in a non-quasistatic way (so during this change the system may be very far out of thermal equilibrium and then the entropy, pressure and temperature may not exist).

The fundamental thermodynamic relation implies many thermodynamic identities that are valid in general, independent of the microscopic details of the system. Important examples are the Maxwell relations and the relations between heat capacities.

Thermodynamic entropy is central in chemical thermodynamics, enabling changes to be quantified and the outcome of reactions predicted. The second law of thermodynamics states that entropy in an isolated system – the combination of a subsystem under study and its surroundings – increases during all spontaneous chemical and physical processes. The Clausius equation of $\delta_{qrev}/T = \Delta_S$ introduces the measurement of entropy change, Δ_S . Entropy change describes the direction and quantifies the magnitude of simple changes such as heat transfer between systems – always from hotter to cooler spontaneously.

The thermodynamic entropy therefore has the dimension of energy divided by temperature, and the unit joule per kelvin (J/K) in the International System of Units (SI).

Thermodynamic entropy is an extensive property, meaning that it scales with the size or extent of a system. In many processes it is useful to specify the entropy as an intensive property independent of the size, as a specific entropy characteristic of the type of system studied. Specific entropy may be expressed relative to a unit of mass, typically the kilogram (unit: Jkg−1K−1). Alternatively, in chemistry, it is also referred to one mole of substance, in which case it is called the molar entropy with a unit of Jmol−1K−1.

Thus, when one mole of substance at about 0K is warmed by its surroundings to 298K, the sum of the incremental values of qrev/T constitute each element's or compound's standard molar entropy, an indicator of the amount of energy stored by a substance at 298K.[6][7] Entropy change also measures the mixing of substances as a summation of their relative quantities in the final mixture [8].

Entropy is equally essential in predicting the extent and direction of complex chemical reactions. For such applications, ΔS must be incorporated in an expression that includes both the system and its surroundings,

$$\Delta_{Suniverse} = \Delta S_{surroundings} + \Delta S_{\ system}$$

This expression becomes, via some steps, the Gibbs free energy equation for reactants and products in the system:
Δ_G [the Gibbs free energy change of the system] = Δ_H [the enthalpy change] −T Δ_S [the entropy change] [6]. In the chemical engineering, the principles of thermodynamics are commonly applied to "open systems" i.e. those in which heat, work, and mass flow across the system boundary.

Flows of both heat ($\dot{Q}$) and work, i.e. W_s (shaft work) and P(dV/dt) (pressure-volume work), across the system boundaries, in general cause changes in the entropy of the system. Transfer as heat entails entropy transfer $\dot{Q}\ /\ \dot{T}$, where $\dot{T}$ is the absolute thermodynamic temperature of the system at the point of the heat flow.

If there are mass flows across the system boundaries, they will also influence the total entropy of the system. This account, in terms of heat and work, is valid only for cases in which the work and heat transfers are by paths physically distinct from the paths of entry and exit of matter from the system [9,10].

To derive a generalized entropy balanced equation, we start with the general balance equation for the change in any extensive quantity Θ in a thermodynamic system, a quantity that may be either conserved, such as energy, or non-conserved, such as entropy.

The basic generic balance expression states that dΘ/dt, i.e. the rate of change of Θ in the system, equals the rate at which Θ enters the system at the boundaries, minus the rate at which Θ leaves the system across the system boundaries, plus the rate at which Θ is generated within the system. For an open thermodynamic system in which heat and work are transferred by paths separate from the paths for transfer of matter, using this generic balance equation, with respect to the rate of change with time of the extensive quantity entropy S, the entropy balance equation is

$$\frac{ds}{dt} = \sum_{k-1}^{k} Mk * Sk + \frac{Q}{T} + Sgen \qquad (2.2)$$

Where;

$$\sum_{k-1}^{k} \breve{M}k * \check{S}k \qquad (2.3)$$

the net rate of entropy flow due to the flows of mass into and out of the system (where $\check{S}$= entropy per unit mass).

$\dot{Q} \,/\, \dot{T}$ = the rate of entropy flow due to the flow of heat across the system boundary [11].

$\widetilde{Sgen}$ = the rate of entropy production within the system. This entropy production arises from processes within the system, including chemical reactions, internal matter diffusion, internal heat transfer, and frictional effects such as viscosity occurring within the system from mechanical work transfer to or from the system.

Note, also, that if there are multiple heat flows, the term $\dot{Q} \,/\, \dot{T}$ will be replaced $\sum Q_j \,/\, T_J$ by where Q_j is the heat flow and T_J is the temperature at the jth heat flow port into the system.

The fundamental equation of thermodynamics for a system containing n constituent species, with the i-th species having Ni particles is, with additional terms:

$$du = \mathrm{TdS} - \mathrm{PdV} + \sum_i^n \mathrm{\mu idNi} + \Phi dQ + vdp \qquad (2.4)$$

U is internal energy, T is temperature, P is pressure, V is volume, μ_i and Ni are the chemical potential and number of molecules of the chemical,Φ and Q are electric potential and charge,v and p are velocity and momentum.

Solving for the change in entropy we get:

$$dS = \frac{1}{T}\mathrm{dU} + \frac{P}{T}\mathrm{dV} - \sum_i^n \frac{\mathrm{\mu i}}{T}\mathrm{dNi} - \frac{\Phi}{T}dQ - \frac{v}{T}dp \qquad (2.5)$$

There is a minuscule change in internal energy for any change in entropy (ds will change by 1/T*dU). But in theory, the entropy of a system can be changed without changing its energy. That is done by keeping all variables constant, including temperature (isothermally) and entropy (adiabatically). That is easy to see, but typically the energy of the system will change. e.g. You can attempt to keep volume constant but you will always do work on the system, and work changes the energy [12].

3. Results and Discussions

The aim of this study is to do a calculation for optimization with info belong to 40 pinch point specified from over existing workable plant. Each pinch point is to defined and stated according to PID drawing belong to plant. Please see figure 2.3. In the first step, the experience-based values for the pressure of pinch point are selected and held constant during this step. Please see table 3.1. for Thermodynamic value of exist plant before calculation. In the second step, for the energy analysis of plant is to executed some calculation to find the largest power loss of plant with mass and entropy value according to first law of thermodynamic. Below mentioned calculation is to do for steam turbine;

Q_{loss} = mbt1*hbt1+mbt2*hbt2+mbt3+hbt3 –

mbt5*hbt5-mbt6*hbt6-wt (3.1)

Q_{loss} = 1.660,6 Kw

Energy loss due to high temperature;

T_0=25 oC=298 K T_K=298 oC=573 K

$E_{Qturbin}$e= Q_{loss}*(1-T_0/T_K) (3.2)

$E_{Qturbine}$= 796,97 Kw

Also this calculation method must implement for all unit according to table 3.2. In this calculation method, the result shows that were more less ratio to usable energy amount of lost energy amount. But this case of plant will be compared with second law of thermodynamic for more affect result. Please see table 3.2. for energy loss of exist plant after calculation.

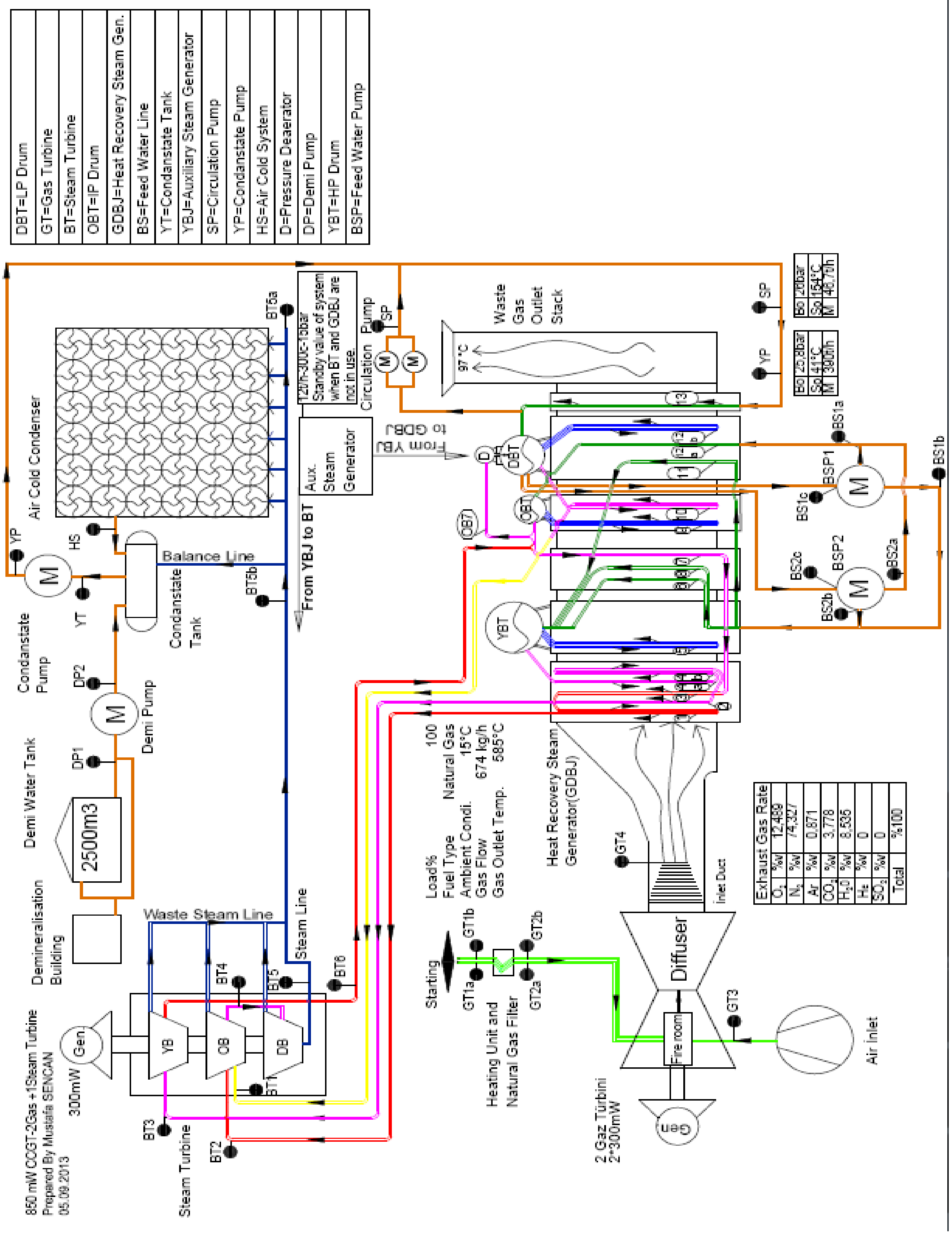

Figure 4. General heat balance arrangement of exist plant

Table 1.Thermodynamic value of exist plant before calculation

Pınch Point	Bar	^{0}C	Mpa	M^3/kg	KJ/Kg	KJ/Kg	KJ/KgK	Ton/h
	P_0	T_0	P_0	(v)	(u)	(h)	(s)	(m)
1/Bt1	4,87	235	0,49	0,45467	2691,6	2918,92	7,1879	35,3
2/Bt2	28,2	560,1	2,82	0,12595	3214,74	3592,56	7,4005	320
3/Bt3	128,8	552	12,9	0,029	3126,1	3476,5	6,6317	261
4/Bt4	5,5	285	0,55	0,4651	2778,3	3032	7,3607	354,5
5/Bt5	0,068	38,5	0,0068	14,67	2437,2	2373,5	8,1488	356,4
6/Bt5a	0,068	38,5	0,0068	14,67	2437,2	2373,5	8,1488	356,4
7/Bt5b	0,068	38,5	0,0068	14,67	2437,2	2373,5	8,1488	356,4
8/Bt6	29,2	334	2,92	0,087746	2816,32	3079,56	6,6838	258
9/Bs1a	62	165	6,2	0,03242	2589,9	2784,6	5,8902	289,6
10/Bs1b	62	165	6,2	0,03242	2589,9	2784,6	5,8902	289,6
11/Bs1c	5,45	161,7	0,55	0,3748	2560,7	2748,1	6,8207	387,1
12/Bs2a	163	165	16,3	0,0932	2401,4	2588,3	5,2238	289,6
13/Bs2b	163	165	16,3	0,0932	2401,4	2588,3	5,2238	289,6
14/Bs2c	5,45	161,7	0,55	0,3748	2560,7	2748,1	6,8207	387,1
15/yt	0,862	38,4	0,09	1,6941	2505,6	2675	7,3589	361
16/yp	25,8	41	2,6	0,079	2602,1	2801,9	6,255	390
17/sp	26	154	2,6	0,079	2602,1	2801,9	6,255	46,7
18/hs	0,2	60	0,02	7,812	2464,8	2620,7	7,6153	52,33
19/Dp1	1	15	0,1	14,67	2437,2	2583,9	8,148	50
20/Dp2	8	15	0,8	2,6218	2492,16	2657,12	7,499	50
21/Ob7	25,3	310	2,5	0,10328	2789,32	3056,56	6,7245	18,6
22/13	26	154	2,6	0,079	2602,1	2801,9	6,255	46,7
23/12-b	10	209	1	0,21083	2638,1	2849	6,7372	35,64
24/12-a	67	275	6,7	0,030928	2587,2	2781	5,8675	271,9
25/11	205	275	20,5	0,005275	2065,32	2107,9	4,4379	271,9
26/10	5,5	162	0,55	0,03595	2593,45	2789,4	5,9319	35,1
27/9	40	277	4	0,05461	2668,9	2887,3	6,2312	35,64
28/8	205	275	20,5	0,005275	2065,32	2107,9	4,4379	271,9
29/7	29,2	334	2,92	0,0877	2816,32	3079,56	6,6838	258,5
30/6	205	275	20,5	0,005275	2065,32	2107,9	4,4379	271,9
31/5	150	368	15	0,012235	2560,4	2924	5,522	261
32/4a	132,9	333,1	13,3	0,013496	2496,7	2662,9	5,339	261
33/4b	132,3	410	13,2	0,0212	2839,24	3104,6	6,1359	261
34/3	29,1	509	2,91	0,11945	3143,98	3502,32	7,298	320
35/2	131,1	476	13,1	0,01975	2699,4	3219,5	6,2808	261
36/1	28,2	560,1	2,82	0,1341	3215,86	3594,1	7,4288	320
37/dbt	5,5	162	0,55	0,3452	2563,75	2752,15	6,79	351
38/obt	30,6	236,7	3,1	0,0667	2603,2	2803,2	6,1856	61,56
39/Ybt	132,9	333,1	13,3	0,212	2839,24	3104,6	6,1359	261
40/d(Degazör)	5,5	184	0,55	0,3452	2563,75	2752,15	6,79	35,1

P_0 =Operation Pressure, T_0 =Operations temperature , v = specific volume, u = internal energy, h =Entalpy, s =Entropy, m =Flow

In the third step, for the exergy analysis of plant is to used operations parameters to improvement of the efficiency of plant (CCGT). To fix the largest power loss of units is to used enthalpy and entropy value for calculation according to second law of thermodynamic.

For 1 st point;

$(e_{chemical}). = -R_{H2O}T_0 \ln(P_d/P_0)$

$(P_d = 0{,}0317$ Bar $P_0 = 0{,}088$ Bar)

$(e_{chemical}). = -0{,}462*298*\ln(0{,}0317/0{,}088)$

$(e_{chemical}).\ _{h2o} = 176{,}44$ kj/kg

$(e_{tm*})_{Bt1} = (h_{Bt1}-h_0) - T_0(S_{Bt1}-S_0)$

$(e_{tm*})_{Bt1} = (2918{,}92-104{,}5)-298(7{,}1879-0{,}3545)$

$(e_{tm*})_{Bt1} = 778{,}1$ kj/kg

$(e_{total})_{Bt1} = (e_{tm})_{Bt1}+(e_{chemical})_{h2o}$

$(e_{total})_{Bt1} = 778{,}1+176{,}44$

$(e_{total})_{Bt1} = 954{,}54$ kj/kg

$(e_{total})= 954,54$ kj/kg *(67780/3600) kg/s

$(e_{total})=17971,86$ Kw

Also this calculation method must implement for all pinch point according to table 3.3. In the figure 3.3. for thermodynamic value of exist plant after calculation. In this calculation method, the result shows that was more much ratio to usable energy amount of lost energy amount.

*tm = thermomechanical

Table 2. Energy loss value of plant

Unit	Energy Loss (kW)	%Loss
Steam Turbine	796,97 Kw	-1,85
Condenser	7.127,79 Kw	-16,57
Condensate Tank	4.567,57 Kw	-10,62
Demi Line	-16,78 Kw	0,04
Feed Water Pump 1	-16.030,01 Kw	37,26
Feed Water Pump 2	-12.710,53 Kw	29,54
HP Drum	238.307 Kw	-553,92
IP Drum	818,413 Kw	-1,90
LP Drum	-265.882,31 Kw	618,2
Totally	-43021,89	100

In the fourth step, total energy loss value will be calculated according to below mentioned calculation method for each unit. Please see chart 3.4. for total loss for each unit and percentage before calculation.

Below mentioned calculation is to do for steam turbine;

$e_{loss}= e_{in}- e_{out}$

$e_{loss} = e_{Bt1}+e_{Bt2}+e_{Bt3} – (e_{Bt5+}e_{Bt6})$

$e_{loss} =333951$ kW

Efficiency loss of plant is steam turbine and high pressure drum. So optimization should be carried out over this unit significantly.

Table 3.Thermodynamic value of exist plant after calculation

Pinch Point	Chemical Exergy (kJ/kg)	Thermo mechanical Exergy (kJ/kg)	Total Loss of Exergy (kW)
1/Bt1	176,45	778,1	17971,86
2/Bt2	176,45	1388,35	278706,8
3/Bt3	176,45	1501,39	243286
4/Bt4	176,45	839,65	200113,8
5/Bt5	176,45	-53,70	24306,68
6/Bt5a	176,45	-53,70	24306,68
7/Bt5b	176,45	-53,70	24306,68
8/Bt6	176,45	1088,93	181706,9
9/Bs1a	176,45	1030,46	97088,51
10/Bs1b	176,45	1030,46	97088,51
11/Bs1c	176,45	716,67	96034,39
12/Bs2a	176,45	1032,75	97272,51
13/Bs2b	176,45	1032,75	97272,11
14/Bs2c	176,45	716,67	96034,39
15/yt	176,45	483,2	66146,11
16/yp	176,45	939,51	120844,9
17/sp	176,45	939,51	14470,4
18/hs	176,45	352,48	7688,46
19/Dp1	176,45	156,93	4630,23
20/Dp2	176,45	423,55	8333,31
21/Ob7	176,45	1053,8	6356,24
22/13	176,45	939,51	14470,4
23/12-b	176,45	842,45	10087,06
24/12-a	176,45	1033,62	91393,6

25/11	176,45	786,54	72732,25
26/10	176,45	1022,83	23385,86
27/9	176,45	1031,54	11959,04
28/8	176,45	786,54	72732,25
29/7	176,45	1088,92	90860,5
30/6	176,45	786,54	72732,25
31/5	176,45	1279,58	105561,8
32/4a	176,45	1073,1	90585,78
33/4b	176,45	1277,23	105391,1
34/3	176,45	1328,66	133786,4
35/2	176,45	1348,96	221183,4
36/1	176,45	1381,46	276959,8
37/dbt	176,45	729,87	88365,32
38/obt	176,45	961,03	19450,77
39/Ybt	176,45	1277,24	105392
40/d(Degazör)	176,45	729,87	8836,53

Table 4. Total loss for each unit and percentage

Unit	Energy Loss (kW)	%Loss
Steam Turbine	333951	54,2
Condenser	235618	38,2
Condensate Tank	193182	31,4
Demi Line	-3703,08	-0,6
Feed Water Pump 1	-98142,6	-15,9
Feed Water Pump 2	-98509,8	-16
HP Drum	233173	37,9
IP Drum	6235,9	1
LP Drum	-185791	-30,2
Totally	616013,3	100

4. Conclusion and Outlook

The aim of this studies is to outline design of plant and the explain the recycle, energy, exergy, engineering, heat transfer problems that have been encountered.

The biggest aim of in this study is to define the energy loss according to working unit. From this point of view, biggest energy loss belongs to steam turbine and innovation opinion should be from over steam turbine unit. Steam turbine is area where consists of physical movement.

By the effect of magnetic field force lines in generator with motion of rotor are to occur opposite force to the moving direction, while mechanical friction coefficients of the simultaneous physical first movement playing a very important role. Therefore, motion ability of power transmission and opposite line force in the generator during energy generation should be revised. Please see the figure 4.1. for energy loss of each unit.

As a result, thermodynamic optimization should be applied over the plant to improvement of largest energy losses. The pass time of heat transfer should develop between the steam turbine and high pressure drum. If heat transfer can reach the required pressure and temperature earlier, waiting time and loss energy will be decreased and serious yield will be provided to the natural source. But for this result should do serious studies in the world.

The existing energy analysis with the expert's studies in order to facilitating the detection of the any workspace can compare to achieve the fast result.

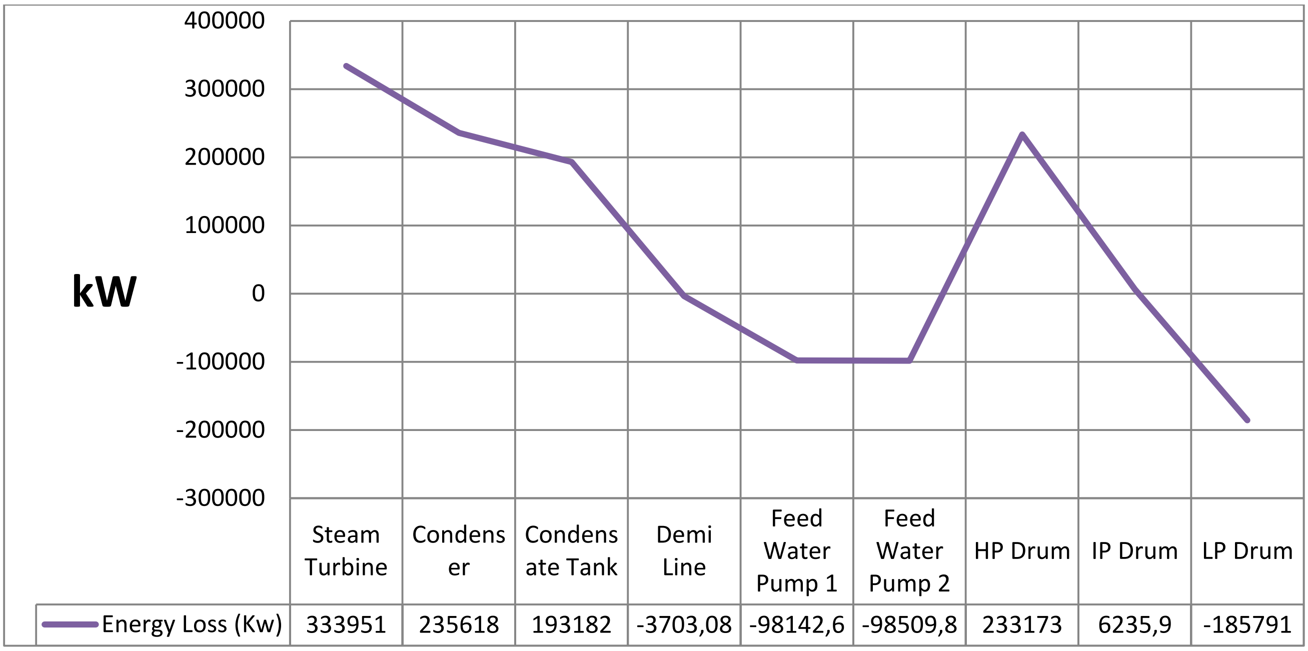

Figure 4.1. Energy loss for each unit as kW

5. Reference

[1] IEA, International Energy Agency (IEA).World Energy Outlook 2012 Factsheet, 2012.

[2] Wall G., Gong M. Exergy Analysis versus Pinch Technology. Proceedings of ECOS'96, Stockholm, Sweden, 1996; 451-455.

[3] Bejan A., Tsatsarinos G., Moran M.Thermal Design and Optmization. Jhon Wiley and Sons, (1996).

[4] John D. Oxford Dictionary of Physics. Oxford University Press. 2005.

[5] E; Saha E, Sourabh L, Jayannavar A. M. Entropy production theorems and some consequences. Physical Review; The American Physical Society: 2009; 1-10.

[6] Moore J. W., Stanistski C. L., Jurs P. C. Chemistry, The Molecular Science. Brooks Cole, 2005. ISBN 0-534-42201-2.

[7] Jungermann, A.H. Entropy and the Shelf Model: A Quantum Physical Approach to a Physical Property. Journal of Chemical Education; 2006; 83 (11): 1686–1694

[8] Levine, I. N. Physical Chemistry, 5th ed. McGraw-Hill; 2002, ISBN 0-07-231808-2.

[9] Born, M. Natural Philosophy of Cause and Chance, Oxford University Press, London, 1949; 44: 146–147.

[10] Haase, R. Survey of Fundamental Laws, Chapter 1 of Thermodynamics,1971; 1:1–97 ISBN 0122456017, ed. W. Jost, of Physical Chemistry. An Advanced Treatise, ed. H. Eyring, D. Henderson, W. Jost, Academic Press, New York, p. 35.

[11] Sandler, Stanley, I. Chemical and Engineering Thermodynamics. John Wiley & Sons. 1989; ISBN 0-471-83050-X.

[12] Dincer, Cengel. Energy, entropy and exergy concepts and their roles in thermal engineering. 2001; 116–149.