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Thermodynamic (Energy-Exergy) Analysis Of Nine MW Coal Based Thermal Power Plant Using Entropy Generation Principle.

Kaushalendra Kumar Dubey[#*1], R. S. Mishra[*2]
[#]*D/o Mechanical Engineering, Sharda University, UP-201306, India*
[1]*dubey.kaushalendra@gmail.com*
[*]*D/o Mechanical Engineering, Delhi Technological University, Delhi-110046, India*
[2]*professor_rsmishra@yahoo.co.in*

ABSTRACT: *The global concern about energy and fuel cost,environment safety, availability of conventional sources for power generation and fulfillment of energy demand will enhance the adoption of coal &gas based power plants. The rising attention of efficient and resourceful use of energy will support the adopted power generation techniques. The exergy modeling of thermal systems provide the information about,cause of losses, to scale the process, and rectifying the components.In this paper, a thermodynamic analysis of coal based nine MW thermal power plant is carried out. The energy-exergy analysis have been carried out for the boiler, turbine, condenser and pump majorly. The result of thermodynamic analysis is computed in terms of 24.12% plant energy efficiency, 35% of plant exergy efficiency and 11% of boiler energy efficiency respectively. The various exergy destruction in the components have been presented in this paper.*

Keywords: *Energy-Exergy Analysis, ,Irreversibility Analysis,. Rankine thermal power plant.*

I. INTRODUCTION

The large amount of heat is transferred between all utilities of thermal power plant and its greatly affect the plant performance. The First Law of Thermodynamic (FLT) is quantative evaluation of energy, it treat the work and heat interaction with equivalent forms of energy between system and surrounding. The FLT does not provide the information about internal losses, thermal inefficiency due to high grade energy of plant dump in to atmosphere and sustainability. The real performance of thermal system and quality of energy transfer process estimated by the approach of Second Law of Thermodynamic (SLT) called concept of exergy. The term 'Exergy'is maximum possible work obtained from a system at a given state when interacting with a environment, its useful quantity that extract from the SLT. It clearly indicates the inefficiencies of a process by locating the degradation of energy. In short exergy efficiency is true or real efficiency and energy efficiency is approximation of real efficiency. The energy-exergy analysis of 9 MW small size of coal based thermal power unit refers live operational data (Average monthly data of February 2015) of Adani Power Gujrat State of India in present analysis. Major units of plant (boiler,turbines,condensar and pump) have been investigated in proposed thermodynamic model. The main objective of energy-exergy modeling to identifying the magnitude of process, cause of losses and rectifying the components. The numerous researches have been conducted on energy-exergy analysis of various thermal systems, power plant components, and renewable energy conversion systems. Dicer and Rosen [2] stated that, why exergy is important for thermal analysis?.They stated that exergy flow rate of a flowing commodity is the maximum rate of work which is obtained from it and it passes reversibly to the environmental state, exchanging heat and materials only with the surroundings. exergy analysis is the theoretical limitations imposed upon a system, clearly pointing out that no real system can conserve exergy and that only a portion of the input exergy can be recovered. Also, exergy analysis quantitatively specifies practical limitations by providing losses in a form in which they are a direct measure of lost exergy.A.Bejan [3] introduced EGM (entropy generation minimization) method, and concluded whenever entropy production is minimized, useful energy is maximized. Khaliq and Kaushik [5] concluded the combustion chamber exergy destruction is 50% of overall exergy destruction of cycle, and effect of intermediate pressure-ratio and effect two stage of reheating on combined GT-ST power cycle performance by using 2nd law thermodynamic approach. Yang et al [6] compared conventional and advanced approach of exergy analysis of supercritical coal thermal power plant. Conventional approach identified exergy destruction of all components, whereas advanced exergyanalysis conclude thermodynamic interactions among thermal utilities for energy saving potential. Ahmadi and Dincer [7] analysed efficiency of dual pressure combined cycle power plant (CCPP),1st law and 2nd law thermodynamic efficiencies are reduced with the addition of duct burner to HRSG, but power output of CCPP is improved. S.C.Kaushik et al and Aljundi [8,9] review begins with concept of exergy, entropy generation, irreversibility of thermodynamic system and exergy destroyed, and and identify the components having major energy-exergy losses in steam power plant. Gulhane and Thakur [10] investigated amount and source of irreversibilities in 35 TPH capacity of boiler. And also found 76% of exergy destruction at peak load on boiler but 1st and 2nd law efficiency are enhanced. Osueke et al [11] computed maximum exergy destruction 87.3% in boiler, and plant exergy efficiency 11.03% with the effect of water flow in boiler on steam generation and plant output of 75MW of steam power plant,which is located in Sapele-Nigeria. R kumar [12] critically summarized in review of 4-E (energy,exergy,exergonomic and economic) concept for different-different power generation techniques. He addressed the boiler and condenser component have major exergy destruction in case of rankine power cycle, whereas combustion chamber is larger part for exergy destruction in case of gas-turbine power cycle.

II. BRIEF OF STEAM POWER PLANT

The working of coal fired thermal power plant based on Rankine thermal power cycle. The plant size have medium level consisted by major parts 01 boiler unit,03 turbine unit,02 dearators,01 condenser unit, 02 HP heaters,01 pump,etc. Another thermal utilities also provide, the detail of plant layout, dimensions and flow rate values of units are not available due to company privacy policy. The proposed energy-exergy analysis is modeled for major parts of Rankine cycle,boiler,turbines, condenser and pump as per operational data of plant. The plant data is collected in month of February 2015,which is shown in table-1 (a) &(b).

Table-1 (a) Operation data of 9MW steam power plant

Time	CW FLOW	Temperature		Ambient Conditions			Condenser		
		CW - IN	CW - OUT	DBT	RH%	WBT	Vacuum	Temp	Flow
	(m^3/hr)	(ºC)	(ºC)	(ºC)	(%)	(ºC)	(Kg/cm^2 g)	(ºC)	(TPH)
10:30 AM	2350	29	40	26	57	19.9	-0.93	44.85	15.1
11:00 AM	2350	29	40	28	50	19.9	-0.93	44.96	15.3
11:30 AM	2371	29	40	28	49	19.8	-0.94	43.79	13.9
12:00 PM	2382	29	40	29	47	20.4	-0.94	44.11	14.2
12:30 PM	2383	28.5	40	29	46	20.3	-0.94	43.43	14.3
1:00 PM	2389	28.5	40	28	54	20.8	-0.94	42.13	10.5
1:30 PM	2392	28.5	40	28	54	21.1	-0.94	42.62	11.9
2:00 PM	2382	28.5	40	29	47	20.6	-0.94	43.56	15.1
2:30 PM	2387	28	39	28	46	19.9	-0.94	42.43	12.5

Table-1 (b) Operation data of 9MW steam power plant

Time	Inlet Steam			Extraction 1 & 2			Extraction 3		
	Pressure	Temp	Flow	Pressure	Temp	Flow	Pressure	Temp	Flow
	(Kg/cm^2 g)	(ºC)	TPH	(Kg/cm^2 g)	(ºC)	TPH	(Kg/cm^2 g)	(ºC)	TPH
10:30 AM	61.81	472	68.02	14.21	322.21	15.69	2.53	181.58	39.87
11:00 AM	61.64	473.6	68.90	14.16	324.0	15.46	2.52	183.65	39.94
11:30 AM	62.06	474.4	68.05	14.05	324.0	15.66	2.52	183.60	39.85
12:00 PM	62.31	473.9	67.87	14.03	321.91	14.87	2.52	182.44	39.22
12:30 PM	62.37	472.92	68.54	14.09	321.8	15.33	2.52	182.26	39.72
1:00 PM	61.57	472.96	70.74	14.27	321.8	18.46	2.52	179.84	43.57

1:30 PM	61.47	477.16	68.74	14.12	328.96	15.53	2.52	186.29	39.72
2:00 PM	61.81	474.09	68.30	14.05	319.08	14.63	2.52	180.03	38.55
2:30 PM	61.77	474.05	70.08	14.28	324.91	16.20	2.52	183.80	41.05

III. ENERGY AND EXERGY ANALYSIS OF NINE MW COAL BASED THERMAL POWER PLANT

All equations of analysis is adopted from fundamental approach of 1st law and 2nd law of thermodynamics, and properties (enthalpy,entropy,specific heat,specific volume,etc) of steam formation referred from steam property table(cited from www.engineeringtoolbox.com/www.spiraxsarco.com) as per steam condition (superheated and saturated) at different pressure-temperature level. PK Nag [1] and Shappiro [4] given energy-exergy equations for power-plant analysis-

$\eta_{PLANT} = W_{NET} / Q\_{BOILER}$ ……………………………………………………………………………..…….(1)

$W_{NE}=W_{TURBINETOTAL}-W_{PUMP}$……………………………………………………………………….…...…..…(2)

$W_{TURBINETOTAL}=W_{TURBINE\_1}+W_{TURBINE\_2}+W_{TURBINE\_3}$………………………………………….………….....….(3)

$W_{TURBINE\_1}$=m_dot_turbine1_steamflow(h_temp inlet_turbine1-h_temp exit_turbine1)……………………(4)

$W_{TURBINE\_2}$=m_dot_turbine2_steam flow(h_tempinlet_turbine2-h_temp exit_turbine2)……………………(5)

$W_{TURBINE\_3}$ = m_dot_turbine3_steamflow (h_temp inlet_turbine3- h_{2s})……………………..………………..….(6)

From enthalpy and entropy balance equation-

$h_{2s}=h_{f2}+x_2h_{fg2}$…..(X2 is steam dryness fraction at condenser)………………………..…………………..……(7)

s1=s2s=sf2+x2 sfg2………………………………………………....…………………………………..……(8)

h1=h_temp inlet_turbine3 = 2827.18 KJ/Kg….temp at 180 ^{0}C (inlet temp of turbine3)

s1=s2 = 7.353 kJ/kg-K from steam properties at condenser line pressure of 0.098 bar (absolute)

h3=hf3=hf2=184 kJ/kg from steam properties

s4=s3=sf2=0.629 kJ/kg-K

hfg2= 2397.95 kJ/kg

sfg2= 7.591 kJ/kg-K

Sp Volume of saturated steam at condenser line v=0.001009 m3/kg

Put all values of entropy and get x2=0.91 and estimate h2s from eq. no7

h2s=2376KJ/kg

Now total turbine work (mass flow rate of steam for different turbine provide in plant data table-1 (a)&(b),providing all values of enthalpy as per inlet temperatures Values of turbines)

$W_{TURBINE\ TOTAL}$ = 960 kJ/kg or 8.5 MW (flow rate of steam varying daily with time)

$W_{PUMP}=v\times dP=v\times(P_{BOILERLINE}-P_{CONDENSERLINE})$=m_dot_pump(h4shf3)………………………………..,,………(9)

h4s = 184.06 kJ/kg

W_{PUMP}=184 kJ/kg or 437KW at 8.5TPH of water flow through pump

W_{NET} = 8.2-0.43 = 7.77 OR 7.8MW

Heat Generated by boiler

Q_{BOILER}=m_dot_boilersteamflow (h_boiler temp - h4s)………………………………………….…..……(10)

(Steam flow through boiler is 65TPH from data table)

Q_{BOILER} = 3196 kJ/Kg or 58627 KW

For $Q\_{CONDENSER}$ …. $W_{TURBINE\ TOTAL} - W_{PUMP}$ = Q_{BOILER} - $Q\_{CONDENSER}$………………………..…………..(11)

□$_{PLANT}$= W_{NET} / Q_{BOILER} = 24.12%

η_{Boiler}= Q_{BOILER} / Q_{FUEL}

Q_{FUEL} = (m_air + m_fuel)×fuel calorific value…....(4620 kcal/kg as per data)…………………………..(12)

□$_{Boiler}$ = 11%

(13 TPH of coal feeding with 97 TPH of air)

ExergyBalance Equation-

Exergy flow rate of inlet steam-

€$_{f\_1n}$ = m_dot_steam × cp_boiler steam × To $[\frac{Tboiler}{To} - 1 - ln\frac{Tboiler}{TO}]$……………………………………..(13)

(Steam generation inlet temperature is 485±5^{0}C, 75TPH and specific heat of steam 2.21 kJ/kg-k, atmospheric temp To is 298K)

€$_{f\_1n}$ = 387 kJ/Kg or 7715KW

Exergy flow rate of exhaust steam-

€$_{f\_out}$ = m_dot_steam × cp_boiler steam × To $[\frac{Tboiler}{To} - 1 - ln\frac{Tboiler}{TO}]$…………………………………….(14)

(Steam temperatureexhaust is 320 ^{0}C, 75TPH and specific heat of steam 2.21 kJ/kg-k, atmospheric temp To is 298K)

$€_{f\_out}$= 260 KJ/Kg or 5240KW

Rate of exergy decrease- $€_{f\_1n}$ - $€_{f\_out}$= 127 KJ/Kg or 2475 KW……………………………………………….(15)

Rate of exergy loss during steam generation= $\frac{€f\_out}{€f\_in}$ = 0.47………………………………………..…….(16)

Rate of exergy increase of steam = Exergyutilization rate= $€_{f\_Usefull}$

$€_{f\_Usefull}$ = m_dot_steam [h1-h4s-To (s1-s4s)]…………………………………………………….………..(17)

$€_{f\_Usefull}$= 1172.10 KJ/Kg or 23547.5KW

Exergy Destruction in boiler=$€_{Des\_boiler}$ = Rate of exergy increase of steam - Rate of exergy decrease

$€_{Des\_boiler}$=1045.1 KJ/Kg or 21072.5 KW

Exergy flow rate of wet steam to condenser

$€_{wetsteam\ to\ condenser}$ = m_ $_{wet\ steam\ to\ condenser}$ [h2s-hf3-To (s_2-sf_3)]…………………………….……………...…….(18)

(26THP of wet steam passing through condenser)

$€_{wet\ steam\ to\ condenser}$ = 188.25 KJ/Kg or 1350.44 KW

Irreversibility estimation of each components-

I_{RR}= ToΣΔS = To (ΔS_{boiler}+ $\Delta S_{turbine}$+ $\Delta S_{condenser}$+ ΔS_{pump})…………………………………...……….……..(19)

And ΔS = cpln($\frac{Tout}{Tin}$) from 2nd law of thermodynamics………………………………...……….………….(20)

(cp will vary with temperature and pressure condition of working fluid, putting all value of cp and Tout&Tin of components)

I_{RR_Boiler}= To(ΔS)$_{\_boiler}$ = 1086 KJ/Kg

$I_{RR\_turbine}$= To(ΔS)$_{\_turbine}$ = 419 KJ/Kg

$I_{RR\_condenser}$= To(ΔS)$_{\_cond}$ = 124 KJ/Kg

I_{RR_pump}= To(ΔS)$_{\_pump}$ = 61.17 KJ/Kg

Now EDR ratio = $\frac{To\Sigma\Delta S}{Qboiler}$……………………………………………………………….………….….…..(21)

EDR ratio = 0.65

Exergetic efficiency = η_{EX} = 1- EDR_{ratio}…………………………………………...…………..……....….(22)

η_{EX} = 1- EDR_{ratio}= 0.35

Exergy Destruction Rate = $\frac{To\Sigma\Delta S}{Wnet}$………………………………………………………………………….(23)

Exergy Destruction Rate = 2.73

IV. RESULT AND DISCUSSION

The property of steam of parts of plant is taken from steam property chart with variation of pressure-temperature and saturated & superheated state of steam condition as per available data. All values of enthalpy, entropy and specific heat shown in table -2 to Table-5 respectively.

Table-2 Boiler Observation

Pressure	Temp	Flow	Enthalpy	Entropy	Sp Heat
(Kg/cm^2 gauge)	(°C)	(Kg/s)	(kJ/Kg)	(kJ/Kg-K)	(kJ/Kg-K)
61.81	472	18.89	3353.1	6.7778	2.418
61.64	473.6	19.10	3357.32	6.7848	2.415
62.06	474.4	18.9	3358.73	6.7838	2.416
62.31	473.9	18.85	3337.13	6.7796	2.418
62.37	472.92	19.05	3354.68	6.7759	2.42
61.57	472.96	19.65	3355.9	6.7836	2.415
61.47	477.16	19.09	3366.17	6.7981	2.409
61.81	474.09	18.97	3358.23	6.7841	2.415
61.77	474.05	19.46	3358.7	6.7851	2.415
61.87	473.90	19.11	3357.69	6.7833	2.416

Table-3 Condenser observation

Vacuum Pr	Temp	Flow	Enthalpy (KJ/Kg)			Entropy (KJ/Kg-k)			Sp Heat
(Kg/cm^2 gauge)	(°C)	(kg/s)	h_f	h_{gf}	h_g	S_f	S_{fg}	S_g	(kJ/Kg-K}
-0.934	44.85	4.2	164.9	1866.9	2031.8	0.554	5.772	6.326	1.505
-0.933	44.96	4.25	166.6	1885.9	2052.6	0.559	5.831	6.391	1.52
-0.937	43.79	3.35	159.9	1809.7	1969.6	0.553	5.595	6.133	1.459
-0.936	44.11	3.94	161.6	1828.8	1990.4	0.542	5.654	6.197	1.474
-0.939	43.43	3.98	148.1	1771.1	1928.2	0.526	5.478	6.004	1.351
-0.944	42.13	2.92	153.1	1676.1	1824.5	0.497	5.183	5.68	1.397
-0.941	42.62	3.3	159.1	1733.5	1886.7	0.514	5.36	5.874	1.549
-0.937	43.56	4.2	151.5	1809.5	1969.6	0.537	5.595	6.133	1.382
-0.942	42.43	3.48	154.8	1714.5	1866	0.509	5.301	5.18	1.412
-0.94	43.54	3.74	154.8	1752.6	1907.4	0.52	5.419	5.939	1.551

Table-4 Turbine 1& 2 Observation

Pressure	Temp	Flow	Enthalpy	Entropy	Sp Heat
(Kg/cm^2 gauge)	(°C)	(Kg/s)	(kJ/Kg)	(kJ/Kg-K)	(kJ/Kg-K)
14.21	322.21	4.35	3086.33	7.0028	2.202
14.16	324.0	4.29	3090.39	7.0111	2.2
14.05	324.0	4.35	3080.65	7.0148	2.116
14.03	321.91	4.15	3086.14	7.007	2.2
14.09	321.8	4.25	3085.7	7.005	2.201
14.27	321.8	5.12	3085.28	6.999	2.204
14.12	328.96	4.31	3101.38	7.03	2.195
14.05	319.08	4.06	3079.82	6.996	2.203
14.28	324.91	4.50	3092.11	7.01	2.201
14.14	323.19	4.38	3088.65	7.008	2.2

Table-5 Turbine-3 Observation

Pressure	Temp	Mass Flow Rate	Enthalpy	Entropy	Sp Heat
(Kg/cm^2 gauge)	(°C)	Kg/s	kJ/Kg	kJ/Kg-K	kJ/Kg-K
2.53	181.58	11.07	2824.18	7.153	2.097
2.52	183.65	11.09	2828.67	7.164	2.093
2.52	183.60	11.06	2828.57	7.164	2.093
2.52	182.44	11.03	2826.14	7.159	2.095
2.52	182.26	11.03	2825.76	7.158	2.095
2.52	179.84	12.1	2820.69	7.147	2.099
2.52	186.29	11.03	2834	7.178	2.089
2.52	180.03	10.7	2821.09	7.147	2.099
2.52	183.80	11.4	2822.7	7.151	2.098
2.52	182.61	11.17	2826.5	7.159	2.095

The numerical computation of nine MW coal based thermal power plant is carried out and performance parameters in terms of plant efficiency boiler efficiency, exergetic efficiency of plant and irreversibilities in terms of exergy destruction in various components, exergy destruction ratio of plant is shown in table-respectively.

Table-6 Parametric Result

	Thermodynamics Parameters	Computed Results
	Net Out Put (Wnet)	7.8MW
	Total Turbine Out Put (Wturbine)	8.5 MW
	Boiler Heat Generation (Qboiler)	3196KJ/KG
	Plant Efficiency ($\square_{PLANT}$)	24.12&
	Boiler Efficiency ($\square_{BOILER}$)	11%
	Plant Exergy Destruction Rate	2.17
	Plant Exergetic Efficiency ($\square_{EXERGY}$)	35%

V. CONCLUSIONS & RECOMMENDATION

The exergy analysis plays deterministic role in identifying the magnitude of thermodynamic processes , cause of losses and rectifying the exergy destruction rate in the components due to energy saving in components (i.e.boilers, condensers in steam power plant)

1. The maximum exergy destruction(irreversibility) as 34%.
2. Exergy Destruction is found to be 2.17 (which is the based on output analysis) and o.65 based on input.
3. The plant efficiency is 24.12%
4. The second law efficiency is 35%

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Author's Information.

Prof.(Dr.) R.S. Mishra Ph.D-SOLAR ENERGY IIT DELHI-1986., HOD Mechanical Engg in Delhi Technological University,Delhi,India . He has published more than 250 research papers in repute journals & conferences and also written 55 books on ASTROLOGY, VADIC Sciences, FENG SHUAI. Professor Mishra is dynamic personality of area ofsolar thermal system design-development and advanced refrigeration techniques.

Kaushalendra K Dubey is associated with is the Dept of Mechanical Engineering, Sharda University, Greater Noida, India as assistant professor. He is a research fellow of Delhi Technological University, Delhi, India. Author qualification is Master of technology in Thermal Engineering with honor's from JamiaMilliaIslamia, Delhi, India..He has faculty research fellowship from Indian Institute of Technology,Delhi in 2016 in Energy and Heat Recovery Research. Author has published more than 25 research papers in repute journals and conferences and active volunteer for work on energy research and technology through industrial and academic project