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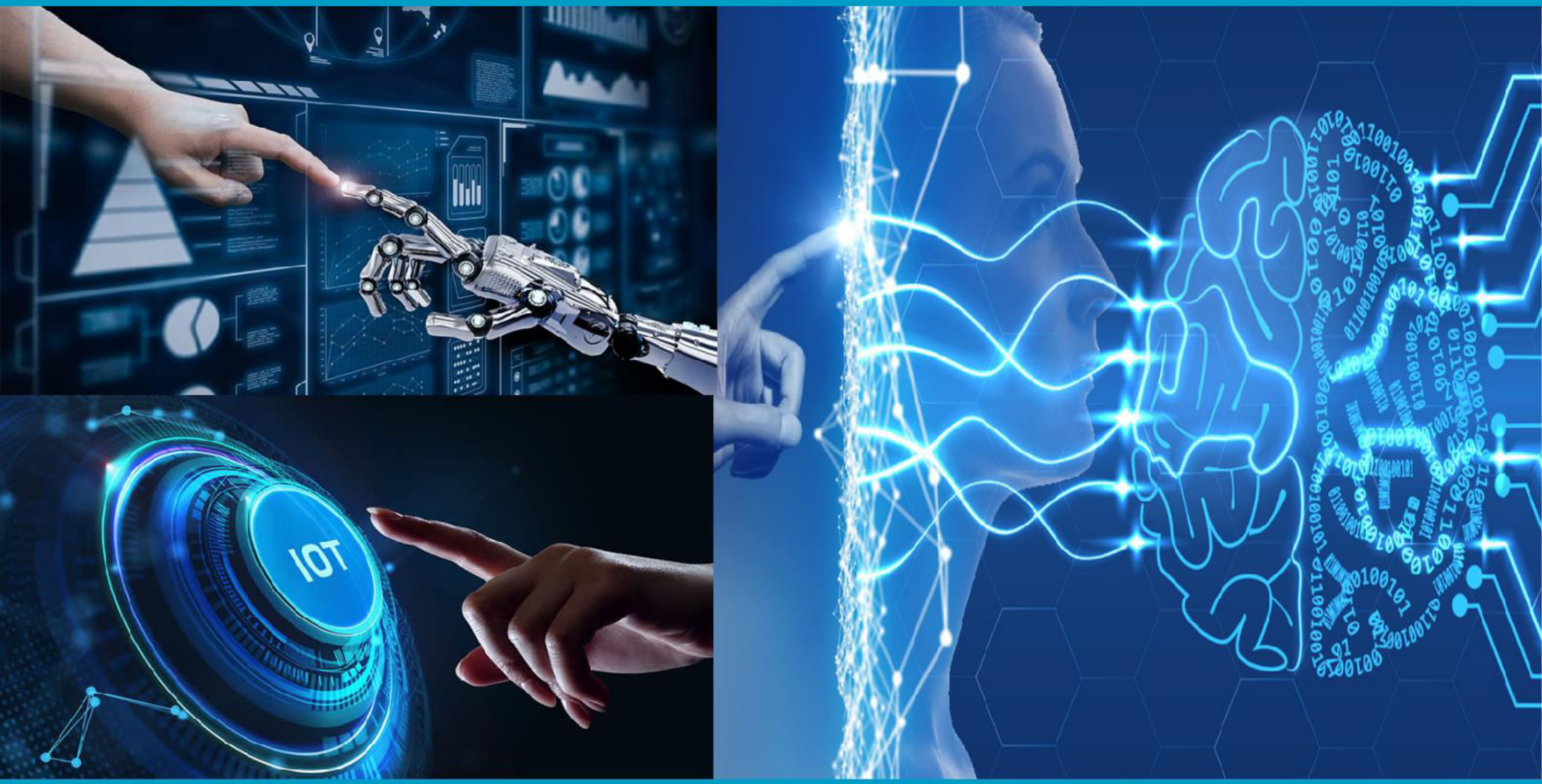

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Assessment of Heat Rate Deviation in a Thermal Power Plant by Analysis of Various Components of Turbine Cycle

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ABSTRACT: To assess heat rate discrepancies in a power plant, a comprehensive analysis of turbine cycle components is conducted. This includes the examination of the HP, IP, and LP turbines, TDBFP, High-Pressure Heater, Low-Pressure Heater, Deaerator, and condenser. The scrutiny involves assessing heat and mass balance, focusing on steam and water flow rates and enthalpy changes in each system. These parameters are crucial for understanding energy transfer and turbine cycle efficiency. Engineers utilize this analysis to identify deviations in heat rate, indicating inefficiencies within components. The interconnected nature of these elements allows for a holistic evaluation, enabling informed decision-making for optimization and maintenance.

KEYWORDS : heat rate, heater, deaerator, turbine components, condenser

I. HIGH PRESSURE HEATER (HPH) ANALYSIS

The provided table offers a detailed assessment of unit-08 within the 660 MW capacity power plant. Specifically focusing on the high-pressure heaters, the energy balance analysis is presented for unit-8 operating at 600 MW. Comparable analyses were carried out for the other two units. The findings highlight the economizer inlet/feed water heater outlet temperature as a critical factor influencing heat rate deviation. A deviation of around 2% in this parameter in a single unit led to notable financial losses, underscoring the importance of monitoring and maintaining optimal temperatures for efficient power plant operation.

Regenerative feedwater heating in modern steam power plants, utilizing a modified Rankine Cycle, achieves higher thermal cycle efficiency (45-50%). Power plants like Koradi Thermal Power Station employ modified Rankine cycles for enhanced efficiency and emission reduction.

UNIT-08 (605MW) (18/01/2023)								
High Pressure Heaters								
			HPH-8		HPH-7		HPH-6	
	Description	Unit	Design	Actual	Design	Actual	Design	Actual
Feed water	Flow	TPH	1804.00	1955.00	1804.00	1955.00	1804.00	1955.00
	Inlet pressure	kg/cm^2	247.00	285.00	247.00	286.00	247.00	288.00
	Inlet Temperature	^{o}C	261.60	261.00	224.20	225.00	184.30	184.20
	Inlet Enthalpy	kJ/kg	1141.60	1139.03	969.56	974.50	794.05	795.79
	Outlet Temperature	^{o}C	298.70	290.00	261.60	261.00	224.20	225.00
	Oultet Enthalpy	kJ/kg	1324.74	1279.05	1141.60	1139.04	969.56	974.57
Steam	Inlet Pressure	kg/cm^2	86.50	85.44	50.60	50.00	25.60	25.00
	Inlet Temperature	^{o}C	410.90	412.40	335.70	335.90	498.30	500.00
	Inlet Enthalpy	kJ/kg	3160.30	3166.45	3031.56	3033.72	3458.67	3463.11

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	Drain Temperature	**^oC**		267.20	268.70		229.80	254.00		189.90	204.00
	Drain Enthalpy	**kJ/kg**		1170.05	1177.61		989.70	1105.17		807.70	870.75
	Feedwater Temp Rise	**^oC**		37.10	29.00		37.40	36.00		39.90	40.80
Energy Balance	**Heat gained by water**	**TPH*(kJ/kg)**		330381.81	273734.22		310350.39	321678.89		316628.81	349523.67
	Mass flow rate of steam	**TPH**		166.00	137.64		137.33	161.63		98.61	107.77

High pressure heater energy balance analysis

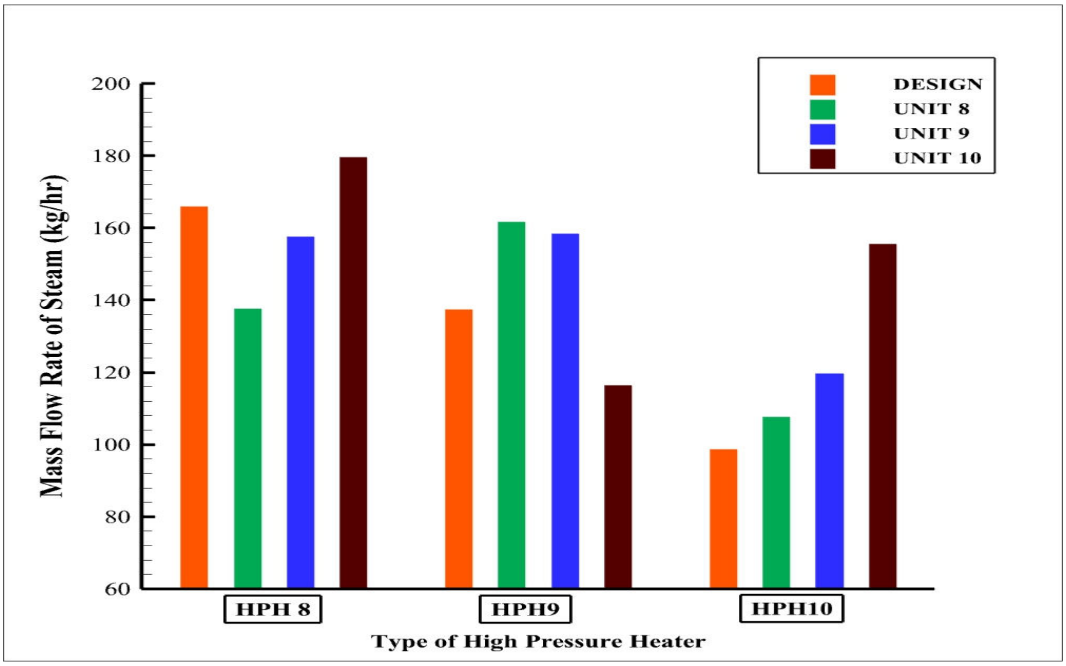

Figure 1 Mass flow rate of steam in all the units

II. TURBINE DRIVEN BOILER FEED PUMP (TDBFP)

The initial assessment of the Turbine-Driven Boiler Feed Pump (TDBFP) identified increased steam consumption by the drive turbine beyond design conditions. Subsequent investigation revealed feed water leakage through the recirculation valve to the deaerator, requiring additional work from the pump under specific loading conditions. A comprehensive analysis, presented in Table , uncovered lower-than-expected efficiency in the TDBFP set, attributed to recirculation valve leakage. To validate steam flow measurements, a reverse calculation technique was employed, exposing instrument calibration errors. Rectifying these errors, confirmed by consistent steam requirements, ensures accurate TDBFP set analysis, optimizing power plant efficiency. The analysis also verified the turbine's efficiency, affirming its proper function. Addressing calibration issues is pivotal for reliable performance evaluation and efficient TDBFP system operation.

TDBFP Performance Report					
Booster Pump Performance					
BFP FW booster pump suction Pressure	kg/cm²	10.81	8.16	9.49	9.49
BFP FW booster pump suction temp	⁰C	182	170	171.6	171.2
BFP FW booster pump discharge pressure	kg/cm²	24	18	18.8	18.8
FW Suction Flow	TPH	1009	747	982.1	982
Hydraulic Power	MW	0.45	0.27	0.32	0.32
Input Power to the Pump	MW	0.57	0.35	0.48	0.48
Test Speed	RPM	1406	1203	1190	1189
Rated Speed	RPM	1406	1203	1203	1203
Pump Capacity at rated speed	TPH	1009	747	972	971
Total dynamic head at rated speed	m	132.1	100	115.9	115.4
Main Pump Performance					
BFP FW suction pressure main pump	kg/cm²	24	18	19	19
BFP FW suction Temperature main pump	⁰C	182	170	171.3	171.3
BFP FW Discharge Pressure	kg/cm²	306	279	224.6	231.8
BFP FW disc temp	kg/cm²	182	177	174.3	174.3
BFP FW discharge flow	m³/hr	1140	833	1080	1083
Total Head Developed(Calculated)	m	3266	2577	2392	2463
Hydraulic Power	MW	10.58	6.61	6.4	6.59
Input Power to the Pump	MW	12.50	8.25	8.69	8.93
TDBFP Pump Set Performance					
Input Power to the Pump given out by turbine	MW	11.38	9.6	12	12
Hydraulic Power	MW	9.45	5.46	5.64	5.85
TDBFP pump set efficiency	%	83.03	56.92	47.03	48.75

		TDBFP-A	TDBFP-A	TDBFP-B	TDBFP-B
Parameters	Unit	Design	Actual	Design	Actual
Inlet Pressure (P1)	kg/cm²	10.08	10.60	10.08	10.60
Inlet Temperature (T1)	0C	359.70	377.00	359.70	377.00
Outlet Pressure (P2)	kg/cm²	0.10	0.10	0.08	0.07
Saturation Temperature (T2s at)	0C	45.28	44.70	40.72	39.17
Dryness fraction		0.96	0.96	0.96	0.96
Inlet Enthalpy (h1)	kJ/kg	3178.97	3214.78	3178.97	3214.78

Figure 3 Booster pump, Main pump and TDBFP Performance analysis

Inlet Entropy (S1)	kJ/kg K	7.34	7.37	7.34	7.37
Inlet sat. Enthalpy (h1s)	kJ/kg	2322.65	2329.27	2291.97	2291.79
For Outlet Enthalpy h2					
Sat. Liquid Enthalpy (hf)	kJ/kg	189.59	187.18	170.54	164.07
Sat. Vapour Enthalpy (hg)	kJ/kg	2582.94	2581.92	2574.82	2572.06
Outlet Enthalpy (h2)	kJ/kg	2494.39	2493.31	2485.86	2482.96
Efficiency (η)	%	79.94	81.48	78.14	79.29
Enthalpy Drop	kJ/kg	684.58	721.47	693.10	731.82

III. DEAERATOR

The evaluation of the deaerator's performance confirms its adherence to expected standards, effectively eliminating dissolved gases from the feedwater. Comparison of anticipated and observed parameters reveals the deaerator's operation within acceptable ranges, with only a slight deviation in feedwater temperature, well within acceptable limits. Key parameters like outlet pressure, oxygen content, and carbon dioxide content meet desired specifications. Importantly, the analysis indicates that the deaerator's impact on overall heat rate deviation is minimal, signifying its negligible contribution to power plant inefficiencies. In conclusion, the deaerator operates satisfactorily, ensuring high-quality feedwater and supporting the power plant's efficient and reliable performance. See detailed analysis in Table.

Deaerator					
	Description	**Unit**		**Design**	**Actual**
Feed Water	**Inlet Flow**	**TPH**		1337.00	1504.00
	Inlet Temperature	**^oC**		145.40	148.70
	Inlet Enthalpy	**kJ/kg**		612.42	626.64
	Outlet Flow	**TPH**		1804.00	1955.00
	Outlet Temperature	**^oC**		178.10	181.00
	Oultet Enthalpy	**kJ/kg**		754.80	767.61
Steam	**Inlet Pressure**	**kg/cm^2**		10.08	10.60
	Inlet Temperature	**^oC**		359.70	377.00
	Inlet Enthalpy	**kJ/kg**		3178.97	3214.78
	HTR-6 Drain Flow	**TPH**		401.95	407.03
	HTR-6 Drain Temp.	**^oC**		189.90	204.00
	HTR-6 Inlet Enthalpy	**kJ/kg**		807.12	870.46

Energy Balance	**EXT steam to Deaerator**	**TPH**		**68.7157**	**63.42576**

Deaerator Energy balance Analysis

IV. LOW PRESSURE HEATERS (LPH)

The Low-Pressure Heater (LPH) functions as a crucial heat exchanger in the power plant, operating at lower pressure levels than its high-pressure counterpart. Utilizing the energy balance equation enables the calculation of the extraction steam flow rate to the LPH, a pivotal parameter in the turbine cycle's heat and mass balance analysis.

The equation, detailed in Table, considers heat transfer between extraction steam and feedwater, factoring in temperatures and flow rates. The extracted steam value obtained from this analysis plays a vital role in conducting an extensive heat and mass balance analysis of the entire turbine cycle.

This comprehensive analysis spans various turbine components, including high-pressure, intermediate-pressure, and low-pressure turbines, as well as the condenser, feedwater heaters, and other relevant elements. The inclusion of the extraction steam value enhances precision, enabling a detailed assessment of turbine cycle performance. This, in turn, facilitates the identification of deviations or areas for improvement in terms of heat rate and overall energy efficiency.

In summary, the Low-Pressure Heater's contribution to the heat and mass balance analysis is pivotal, with the energy balance equation providing insights into the turbine cycle's performance, efficiency, and potential areas for enhancement.

Low Pressure Heaters														
				Heater-4			Heater-3			Heater-2			Heater-1	
	Description	**Unit**		**Design**	**Actual**		**Design**	**Actual**		**Design**	**Actual**		**Design**	**Actual**
Feed Water	**Flow**	**TPH**		1337.00	1504.00		1337.00	1504.00		1337.00	1504.00		1337.00	1504.00
	Inlet Temperature	**°C**		113.30	113.70		80.90	79.60		63.50	62.75		44.40	45.20
	Inlet Enthalpy	**kJ/kg**		475.34	477.04		338.73	333.27		265.80	262.66		185.93	189.27
	Outlet Temperature	**°C**		145.40	148.70		113.30	113.70		80.90	79.60		63.50	62.75
	Oultet Enthalpy	**kJ/kg**		612.42	626.64		475.34	477.04		338.73	333.27		265.80	262.66
Ext. Steam	**Inlet Pressure**	**kg/cm^2**		4.77	4.52		1.84	1.62		0.58	0.58		0.28	0.28
	Inlet Temperature	**°C**		273.00	292.40		172.10	196.20		84.53	84.53		67.00	67.00
	Entropy (S)	**kJ/kgK**		7.39	7.49									
	Sat. Liquid Entropy (Sf)	**kJ/kgK**								1.13	1.13		0.92	0.92
	Sat. Vapour Entropy (Sg)	**kJ/kgK**								7.55	7.55		7.80	7.80
	Sat. Liquid Enthalpy (hf)	**kJ/kg**								353.95	353.95		280.46	280.46
	Sat. Vapour Enthalpy (hg)	**kJ/kg**								2650.54	2650.54		2620.96	2620.96
	Dryness Fraction(x)									0.98	0.99		0.94	0.96
	Inlet Enthalpy	**kJ/kg**		3009.75	3050.39		2815.52	2865.12		2594.73	2629.65		2483.07	2516.29
	Drain Temperature	**°C**		118.90	119.50		86.50	85.80		69.10	52.50		50.00	48.00
	Oultet Enthalpy	**kJ/kg**		499.11	501.6		362.25	359.31		289.25	219.79		209.34	200.98

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Energy Balance	Heat gained by water	TPH*(kJ/kg)		183265.89	224999.38		182657.33	216229.64		97502.27	106195.16		106787.27	110376.09
	Mass flow rate of steam	TPH		73.00	88.28		70.38	81.28		37.75	34.25		40.60	46.02

Low pressure heaters energy balance system

V. CONDENSER

The performance analysis of a condenser involves assessing key parameters such as Terminal Temperature Difference (TTD) and effectiveness. TTD reflects the temperature difference between steam saturation and cooling water outlet, indicating condenser efficiency. A lower TTD signifies superior heat transfer. Effectiveness, the ratio of actual to maximum heat transfer, gauges efficiency, with higher values indicating better performance.

Examining TTD and effectiveness aids in identifying deviations from expected values, highlighting potential issues like fouling or scaling that diminish condenser efficiency. Table 5.19 illustrates condenser performance, where higher TTD or lower effectiveness may signal problems. Fouling, accumulation on heat transfer surfaces, and scaling, mineral precipitation hindering heat transfer, can result from poor water quality or inadequate maintenance.

Regular monitoring enables early detection of performance degradation, prompting timely actions such as cleaning, inspection, or chemical treatment to restore optimal condenser efficiency. These measures counteract reduced heat transfer efficiency, elevated pressure drop, and increased energy consumption, enhancing overall power plant performance.

Routine maintenance practices, including tube cleaning, appropriate chemical treatment, and water quality monitoring, mitigate fouling and scaling, improving condenser efficiency and reducing operating costs. Continuous TTD and effectiveness monitoring serves as an early warning system, allowing prompt intervention to clean the condenser, eliminate deposits, and uphold optimal heat transfer efficiency. Maintaining a well-functioning condenser ensures efficient steam cycle operation, optimal heat transfer, and minimized energy losses, ultimately enhancing overall plant performance.

Condenser							
			HP Shell (LP 2)			LP Shell (LP 1)	
Description	**Unit**		**Design**	**Actual**		**Design**	**Actual**
Steam mass flow rate	TPH		493.62	558.88		491.01	552.31
Turbine Exh. Pressure	kg/cm^2		0.10	0.10		0.08	0.07
CW Inlet Temp	^0C		37.50	31.80		33.00	27.20
CW Outlet Temp	^0C		42.00	38.00		37.50	31.80
Range	^0C		4.50	6.20		4.50	4.60
Saturated Temp	^0C		45.28	44.70		40.72	39.17
Saturated Entropy (Sf)	kJ/kgK		0.64	0.63		0.58	0.56
Saturated Entropy (Sg)	kJ/kgK		8.16	8.17		8.24	8.27
Sat. Liquid Enthalpy(hf)	kJ/kg		189.59	187.18		170.54	164.07
Sat. Vapour Enthalpy(hg)	kJ/kg		2582.94	2581.92		2574.82	2572.06
Dryness Fraction	x		0.90	0.91		0.89	0.90
Latent Heat (hfg)	kJ/kg		2393.35	2394.74		2404.29	2407.99
Heat Duty	TPH*(kJ/kg)		1061186.02	1217998.59		1049741.01	1195398.42
CW mass flow rate	TPH		56147.41	46774.14		55541.85	61873.62

TTD	^0C		3.28	6.70		3.22	7.37
Effectiveness			0.58	0.48		0.58	0.38

Condenser performance analysis

VI. CONCLUSION

In conclusion, the thorough analysis presented in this paper highlights the critical role of various components in the power plant, particularly focusing on the turbine cycle and associated systems. The investigation into the Turbine-Driven Boiler Feed Pump (TDBFP) revealed the significance of addressing instrument calibration errors, underlining the importance of precise measurements for reliable performance analysis. The subsequent examination of the deaerator and low-pressure heater affirmed their satisfactory operation, contributing to efficient power plant performance.

Moreover, the condenser's performance analysis, employing parameters like Terminal Temperature Difference (TTD) and effectiveness, provided valuable insights into its heat transfer efficiency. Regular monitoring and early detection of deviations from expected values enable timely maintenance actions, crucial for optimizing condenser performance and preventing long-term deterioration.

The integrated approach to analyzing these components, considering heat and mass balance, efficiency, and effectiveness, underscores the holistic evaluation necessary for identifying and rectifying performance issues. This methodology facilitates informed decision-making for maintenance, operational enhancements, and overall optimization, ultimately contributing to improved power plant efficiency and reliability.

In essence, the findings emphasize the interconnected nature of turbine cycle components and the importance of meticulous analysis for a comprehensive understanding of power plant performance. The paper underscores the significance of routine monitoring, maintenance, and corrective actions to ensure consistent, efficient operation, minimizing energy losses and enhancing the overall performance of the power plant.

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