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“Innovative methodology to undertake critical analysis of flue gas path to identify & quantify specific air leakages to reduce auxiliary power consumption and reduce net heat rate of thermal power plants, explained through a Case Study”

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Background :

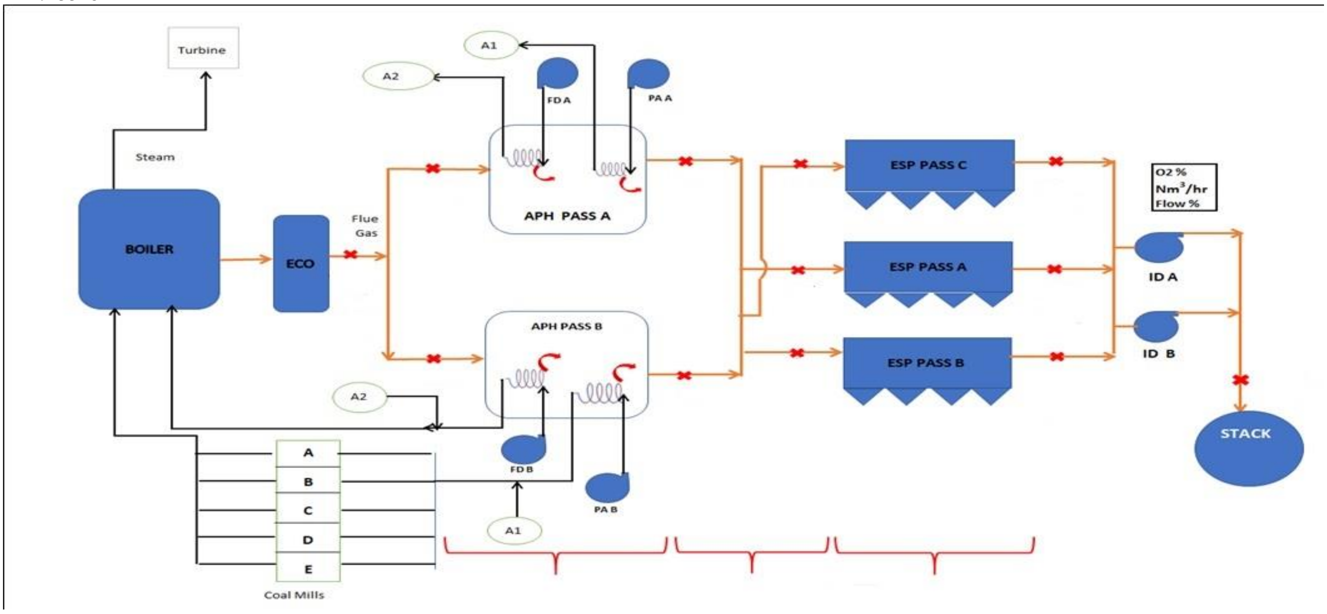
This is a case study of BHEL make Pulverized Coal Fired 430 TPH capacity power boiler in a Integrated power plant generating steam at 138 kg/cm2 and power of 120 MW. As per OEM design, the boiler consisted of 2 pass 4 field ESP’s to cater to the boiler flue gas. Originally, the boiler consisted of 2 pass 4 field ESP’s to cater to the boiler flue gas. But, as over the years, the ESP efficiency deteriorated, the unit installed a third pass ESP to meet the emission norm.

The Rated details of Air quantity supplied to boiler & its share is as below :

Rated air and Gas details from Technical Dairy

Description	Unit	Value	% Share wrt FG QTY	FD, PA Breakup		
Total Combustion air	TPH	532.4	100%			
FD Air (at APH Outlet)	TPH	375.2	70%	375.2	459	86.21%
Primary air (at APH Outlet)	TPH	83.8	16%	83.8		
Tempering Air (cold)	TPH	73.4	14%			

The schematic of the existing boiler setup is as below :



Situation Analysis :

This paper attempts as to how the root cause analysis can be done using the innovative methodology discussed here which can help boilers in improving overall productivity, reduce AP & net heat rates & also increase ESP performance to reduce emissions, explained through a case study.

To know the status, few measurements were conducted for O2%, Temp and static pressure at various locations, APH Inlet & Outlet and ESP Inlet & outlet.

Measurements at ESP Pass A, B & C outlets & Quantification of Gas Volumes in Nm3/hr :

The gas velocity pressures were also measured at all the 3 passes of ESP outlets as per USEPA Traverse point measurement method, along with Gas temp, O2% and static pressure. The Gas velocity and the gas volume was calculated for each pass.

It was observed that the increase in avg O2% was from 2.5% at APH Inlet to 7.2% at ESP outlet. Pass wise measured values at ESP outlet are given in table below :

Measured Values at APH Pass A&B Inlet and ESP Pass A, B & C Outlet of Boiler 1									
Location of measurement		Time	Pass Avg	Overall Avg O2%	Pass Avg	overall Avg Temp	Gas flow		Static Pressure
							Nm3/hr	% SHARE	mmWC
			%	%	deg C	deg C			
APH I/L	Pass A	12:34	2.6%	2.5%	310	311			
	Pass B	12:52	2.5%		312				
APH O/L	Pass A								
	Pass B								
ESP I/L	Pass A								
	Pass B								
	Pass C								
ESP O/L	Pass A	16:25	7.3%	7.2%	138	142	342969	44%	-190
	Pass B	16:45	7.4%		140		240471	31%	-182
	Pass C	16:15	6.9%		149		196239	25%	-187
	AVG/ TOTAL						779679		

The interpretation of measured values reveal the following :

- There is substantial variation in gas volumes (Normalised at 25 degC & hence can be directly compared irrespective of Gas temperature) at outlet of ESP Pass A, B & C which is 44%, 31% and 25% respectively.
- The gas volume handled by ESP pass A is 75% higher than that of ESP C.

Measurements at ESP Inlet & quantification of air leakages in ESP passes :

The measured values of O2%, Gas Temp and static pressure at ESP Inlet Pass A, B & C are given in the table below.

The Normalised Gas volume is extrapolated from the earlier measured gas volumes at ESP outlets, based on change in O2%.

Measurements at ESP Inlet & Extrapolated gas volumes at ESP I/L in Pass A, B & C										
Location of measurement		Time	Pass Avg	Overall Avg O2%	Pass Avg	overall Avg Temp	Gas flow		Leakage volumes	Leakage %
							Nm3/hr	% SHARE	Nm3/hr	
			%	%	deg C	deg C				
APH I/L	Pass A	12:34	2.6%	2.5%	310	311				
	Pass B	12:52	2.5%		312					
APH O/L	Pass A									
	Pass B									
ESP I/L	Pass A	15:24	7.1%	6.1%	146	148	338051	43%	4917	1.5%
	Pass B	15:53	6.9%		142		231944	30%	8527	3.7%
	Pass C	15:38	4.4%		157		166685	21%	29554	17.7%
	AVG/ TOTAL						736681		42999	
ESP O/L	Pass A	16:25	7.3%	7.2%	138	142	342969	44%		
	Pass B	16:45	7.4%		140		240471	31%		
	Pass C	16:15	6.9%		149		196239	25%		
	AVG/ TOTAL						779679			

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The above table reveals the following :

- Based on the gas volumes entering the ESP, there is substantial imbalance in gasflow in ESP pass A, B & C of 43%, 30% and 21% respectively.
- The ESP pass A gets almost double the gas volume entering ESP pass C.
- There is a substantial air leakage in ESP Pass C of 29554 Nm3/hr (17.7% of volume entering the ESP).
- Other 2 ESP passes have negligible leakages 1.5% & 3.7% only.
- It shows that air leakages in ESPs can be practically controlled to a level of 1.5 %.

Measurements at APH Outlet & Quantification of air leakages between APH & ESP :

The measured values of O2%, Gas Temp and static pressure at APH Outlet Pass A & B are given in the table below.

The Normalised Gas volume is extrapolated from the earlier measured gas volumes at ESP outlets, based on change in O2%.

Extrapolated gas volumes at APH O/L in Pass A & B

Location of measurement		Time	Pass Avg	Overall Avg O2%	Pass Avg	overall Avg Temp	Gas flow		Leakage volumes	Leakage %
							Nm3/hr	% SHARE	Nm3/hr	
			%	%	deg C	deg C				
APH I/L	Pass A	12:34	2.6%	2.5%	310	311				
	Pass B	12:52	2.5%		312					
APH O/L	Pass A	13:10	4.0%		160	161	333598	50%		
	Pass B	13:21	5.1%		162		333598	50%		
	AVG/ TOTAL			4.57%			667197		69484	10.4%
ESP I/L	Pass A	15:24	7.1%		146	148	338051	43%	4917	1.5%
	Pass B	15:53	6.9%		142		231944	30%	8527	3.7%
	Pass C	15:38	4.4%		157		166685	21%	29554	17.7%
	AVG/ TOTAL			6.12%			736681		42999	
ESP O/L	Pass A	16:25	7.3%		138	142	342969	44%		
	Pass B	16:45	7.4%		140		240471	31%		
	Pass C	16:15	6.9%		149		196239	25%		
	AVG/ TOTAL			7.2%			779679			

The above table reveals the following :

- The O2% increases from avg 4.57% at APH Outlet to avg 6.12% at ESP inlet, which is certainly due to ingress of air.
- Also, there is substantial drop in gas temp from avg 161 C at APH outlet to 148 C at ESP inlets (more than 13 C), which also indicates substantial ingress of colder atmospheric air at about 25 C.
- Based on the gas volumes leaving the APH & entering the ESP, there is substantial difference in gasflow of 69484 Nm3/hr or 10.4% , which is the leakage of atmospheric air in the area between APH and ESPs.

Quantification of air leakages at APH :

The measured values of O2%, Gas Temp and static pressure at APH Inlet Pass A & B are given in the table below.

The Normalised Gas volume is extrapolated from the earlier measured gas volumes at ESP outlets, based on change in O2%.

Extrapolated gas volumes at APH I/L in Pass A & B and Quantification of air leakages in APH										
Location of measurement		Time	Pass Avg	Overall Avg O2%	Pass Avg	overall Avg Temp	Gas flow		Leakage volumes	Leakage %
							Nm3/hr	% SHARE	Nm3/hr	
			%	%	deg C	deg C				
APH I/L	Pass A	12:34	2.6%		310	311	307055		26543	8.6%
	Pass B	12:52	2.5%		312		286714		46884	16.4%
	AVG/ TOTAL			2.5%			593769		73427	12.4%
APH O/L	Pass A	13:10	4.0%		160	161	333598	50%		
	Pass B	13:21	5.1%		162		333598	50%		
	AVG/ TOTAL			4.57%			667197		69484	10.4%
ESP I/L	Pass A	15:24	7.1%		146	148	338051	43%	4917	1.5%
	Pass B	15:53	6.9%		142		231944	30%	8527	3.7%
	Pass C	15:38	4.4%		157		166685	21%	29554	17.7%
	AVG/ TOTAL			6.12%			736681		42999	
ESP O/L	Pass A	16:25	7.3%		138	142	342969	44%		
	Pass B	16:45	7.4%		140		240471	31%		
	Pass C	16:15	6.9%		149		196239	25%		
	AVG/ TOTAL			7.2%			779679			

The above table reveals the following :

- The O2% increases from avg 2.5% at APH Inlet to avg 4.57% at APH Outlet shows that there is substantial leakages of air delivered by PA and FD fans.
- The % leakage of air in Pass A and Pass B in the APH is 8.6% and 16.4% respectively.
- (As per OEM of APH, about 6%-8% leakage is within allowable limits, accordingly the leakage in pass B APH is substantially higher to 16.4%)
- The APH leakage is quantified to be 73427 Nm3/hr, which is 12.4% , which is far higher than the OEM claim of 6 to 8% .

Overall leakages & Possible reduction in leakages :

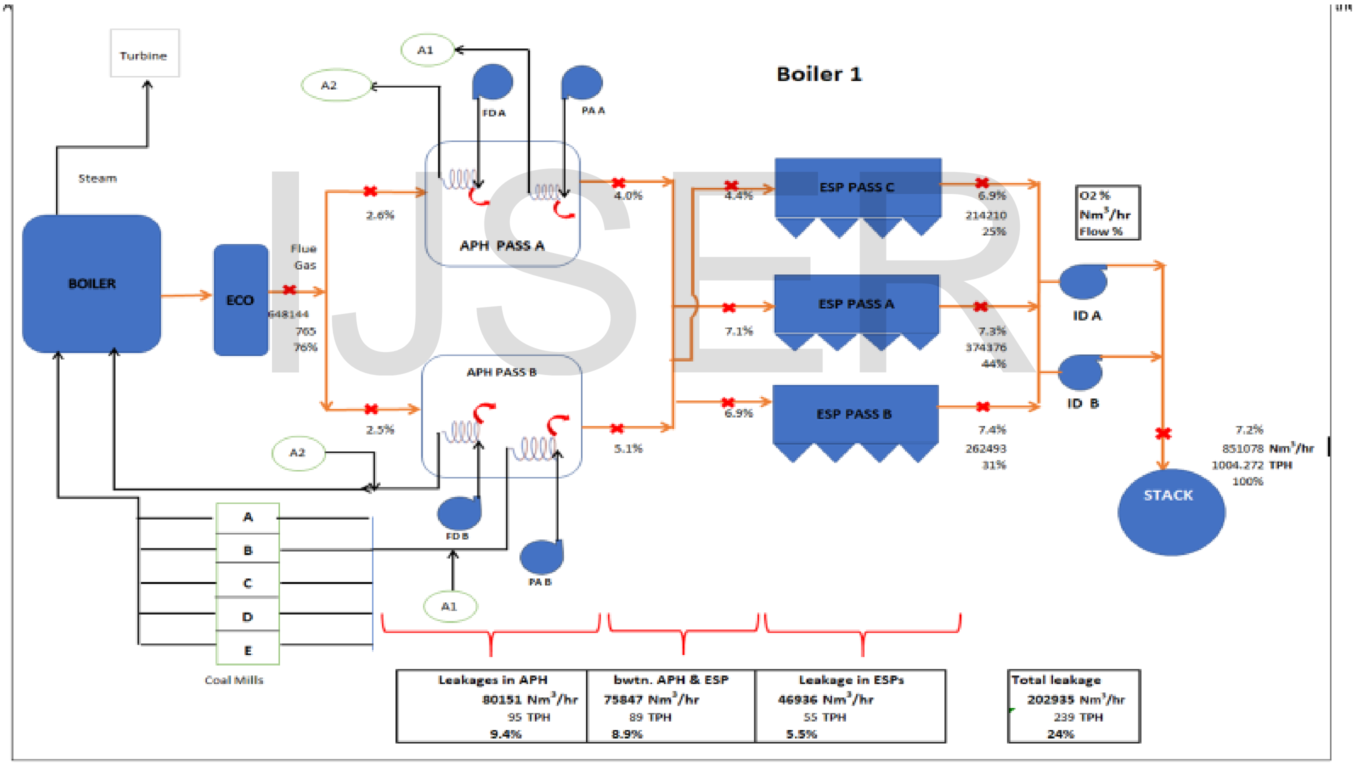
The overall leakages and possible reductions in leakages based on practically achievable allowable limits are given in the table below :

Overall leakages & possible Reduction in leakages to allowable limits								
Location of measurement		Time	Gas flow		Leakage volumes	Leakage %	allowable leakage %	estimated volumes after reducing leakages
			Nm3/hr	% SHARE	Nm3/hr			
APH I/L	Pass A	12:34	307055		26543	8.6%	6%	307055
	Pass B	12:52	286714		46884	16.4%	6%	286714
			593769		73427	12.4%		593769
APH O/L	Pass A	13:10	333598	50%				325478
	Pass B	13:21	333598	50%				303917
	AVG/ TOTAL		667197		69484	10.4%	5%	629396
ESP I/L	Pass A	15:24	338051	43%	4917	1.5%		
	Pass B	15:53	231944	30%	8527	3.7%		
	Pass C	15:38	166685	21%	29554	17.7%		
	AVG/ TOTAL		736681		42999			660865
ESP O/L	Pass A	16:25	342969	44%			1%	
	Pass B	16:45	240471	31%			1%	
	Pass C	16:15	196239	25%			1%	
	AVG/ TOTAL		779679		185910	24%	12.77%	680691

The above table reveals that, based on the gas volume at stack, the overall leakage of air is about 24% , which is substantial. The break-up is as below :

- about 9.4% of the total volume going to stack is the air leakages at APH,
- other 8.9% is atmospheric air leakages between APH and ESP and
- additional 5.5% are the leakages in ESPs.
- These quantities are substantially higher than allowable limit, totaling to 12.8%.
- The leakages could be practically reduced at least by about 11.2% (24-12.8).
- After reducing the leakages, the overall gas volume handled by ID fans will be reduced by about 13% and the proportionate reduction in power consumption by ID fans is expected to be of the order of 10%.

The boiler system showing the gas flow path, O2%, gas volumes and air leakages is provided in Figure below :



Energy savings after reducing air leakages to allowable limits, in KWh/year:

- Presently the leakage of air is happening at 3 locations, the APH, between APH & ESP and at ESP. The present leakages are very much in higher side compared to best practices and OEM suggested values of leakages.
- If the existing be reduced to allowable limit of leakages, in overall the gas volume handled by ID fan would come down by about 12.7 %.

  The comparison of existing and proposed leakage volumes is given below.

Table 12: Existing & New leakage volume

Leakage at	Existing leakage quantity	Proposed Leakage Quantity	Reduction in leakage by	
	Nm3/hr	Nm3/hr	Nm3/hr	TPH
APH A & B	80151	38889	41263	48.69
Between APH & ESP	75847	34352	41495	48.96
Leakage at ESP	46936	21642	25295	29.85
Total leakages	202935	94882	108053	127.5

Reduction in Auxilliary Power Consumption :

- After reducing the leakages as above, the power consumption of ID fan as well as FD & PA fans would reduce proportionate to the reduction in the volumes. The calculation towards the saving are given in the table below

Particular	Unit	ID Fan	FD & PA
ID Fan power consumption	kW	835	1639
Present Flow handled by Fan	TPH	1004	859
Expected reduction in flow to be handled by fan	TPH	128	49
Savings in Fan power consumption	%	13%	6%
ID fan operating duration	hr/year	7920	7920
Electrical Unit Cost	Rs./kWh	3.5	3.5
Correction factor	%	90%	80%
Savings	kW	95	74
	kWh/year	755541	588287
	Rs. Lakhs/year	26	21
Net Savings	kWh/year	1343828	
	Rs. Lakhs/year	47	
Investment	Rs. Lakhs	40	
Simple Payback period	year	1	

Overall Economic Benefits :

- Apart from saving in fan power as discussed above, reduced leakages in APH would improve the hot air temperature supplied to boiler.

- AS per design, the hot air temperature should be about 280 °C (at NCR), whereas the actual temperature about 262 °C, which may improve by estimated 5 to 10 °C.
- This would proportionately improve the boiler efficiency also. Increased quantity of hot air availability to the boiler, would also help increase the steam generation proportionately.
- Implementation of the recommendation would lead to annual saving of Rs. 47 Lakhs. The estimated investment towards reducing the leakages in terms of revamping of leaking seals, man hols, ducts, flanges etc. is assumed to be Rs. 40 Lakhs. The simple payback period would be around 1 year.
- Also, the reduced leakages would mean reduced volume & reduced Gas velocity in ESP, which will improve the performance of ESP, the Coarse Dust would get collected in Field -1, Reduced carry over of coarse dust to Field 2, Improved Fly ash quality in Field 2, 3 ESP Hopper

Conclusion & Recommendations :

- Air leakages in APH & ESPs and also in the section between APH & ESP, leads to increased auxiliary power consumption by ID, FD and PA fans and increased gas velocity in overloaded ESPs and hence reduced residence time for dust particles leading to reduced efficiency of ESPs.
- Also, the boiler and coal mills get lesser quantity TPH of air with lesser temperature of hot air which reduces boiler capacity, increases specific coal consumption and also increases auxiliary power consumption, hence reduced overall productivity of boilers with higher emissions to environment.
- Though all boilers have online recording of O2% at APH Inlet & air TPH quantities supplied to coal mills and to boiler, some also have O2% at stack in their CEMS instrument and that everybody knows there are leakages at APH and ESPs, hardly any actions could be taken to reduce these leakages because the specific quantities and exact locations of individual leakages are not known.
- A root cause analysis can be done using the methodologies discussed here which can help boilers in improving overall productivity & also increase ESP performance.
- The innovative methodology as discussed in the paper through measurements of O2%, Gas temp, Static pressure at APH and ESP inlets & outlets in all passes and Gas volume at any one location in each pass can be applied for critical analysis of the boiler performance.
- In the event of higher emission levels at stack, before going in for adding an ESP field or pass, the root cause analysis should be done, to identify and quantify air leakages and imbalance in gas volumes to each ESP pass.
- Excessive leakages in all places, exceeding allowable limits, shall be plugged.
- Make the gas flow distribution uniform to all ESP passes by appropriately adjusting the dampers such that each ESP gets about equal volume.
- Though, practically it is impossible to make zero leakages in ESP, but about 1.5% leakage is very much possible to achieve.
- It is strongly recommended that the air leakages in bottom hoppers of APH, the poking holes, the manholes, loose flanges and other leakages in the ducts between APH & ESP shall be identified & plugged during all periodic/annual shutdowns and all efforts be made to reduce or rather eliminate these leakages of atmospheric air into the flue gases.
- Also, the reduced leakages would mean reduced volume & reduced Gas velocity in ESP, which will improve the performance of ESP. Maximum Coarse Dust would get collected in Field -1, so reduced carry over of coarse dust to Field 2 and hence improved Fly ash quality in Field 2, 3 ESP Hoppers.

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