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RESEARCH ARTICLE

PROCESS AND ENERGY OPTIMISATION – A CASE STUDY OF UB FGR FANAT CAPTIVE POWER PLANT OF NRL

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ABSTRACT

The old saying "Excellence is the gradual result of always striving to do better……. The noblest search is the search for excellence." – An integrated approach to achieve continuous improvement and reach towards excellence in Utility Boiler Operation. This paper highlights the case study carried out regarding the successful trial run of the Flue Gas Recirculation of the Utility Boiler of Co-generation plant of the Numaligarh Refinery Limited, Golaghat, Assam. This fan could not be put into service since commissioning of the boiler. Once it is successfully taken into service, many positive outcomes are noticed and resulted in the process and energy optimization in the operation of the utility boiler. In Numaligarh Refinery Limited (NRL), Co-generation plant (CGP), Utility Boiler (UB) is used to produce High pressure super-heated steam. One of the accessories named Flue Gas Recirculation (FGR) could not be put into service due to certain problems. FGR is a combustion modification process. As the name implies, a portion of the combustion products exiting the boiler are recirculated and introduced into the primary combustion zone. In UB, there are two nos. of FGR fans. But they could not put into service for a long time since commissioning. After a series of studies and experiments, the problems or factors were identifiedviz. selection of correct UB load at which the fan should be started, dampers adjustment, burner flame stability, etc. After identification and trouble shooting of these problems, the FGR fans could be run successfully and put into continuous service.
Following advantages were achieved in UB after the service of the FGR fans:

- Increases steaming rate of the UB
- Saves Energy (Fuel optimization)
- Reduced harmful NOxgas Emissions
- Increased in flue gas back end temperature
- Lowers Greenhouse gas CO2 emission as the amount of fossil fuel is reduced

Thus the above case study helped one of the important UB accessories to successfully put into service leading to various benefits, flexibility and process optimization in the operation of the UB.

INTRODUCTION

Brief introduction of NRL CGP configuration & Utility Boiler: A boiler is aclosed vessel that provides a means for combustion heat to be transferred into water until it becomes heated water or steam. The hot water or steam under pressure is then usable for transferring the heat to a process. Water is a useful and cheap medium for transferring heat to a process.
A number of items must be fitted to steam boilers, all with the objective of improving:

- Operation.
- Efficiency.
- Safety.

Such items related to boilers are classified as mountings and accessories.

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Boiler mountings are different fittings and devices which are necessary for the operation and safety of a boiler .e.g. pressure gauge, safety valves, steam stop valve, etc Normally these device are mounted over the boiler shell.Boiler Accessories are auxiliary plants or parts required for steam boilers for their proper operation and to increase efficiency of the boiler .e.g. feed pumps, super heater,economizer, etc. In Co-Generation Plant (CGP) or Captive Power Plant (CPP) of Numaligarh Refinery Limited, there are two nos. Gas Turbines (GTG-01 and GTG-02) along with two nos. of Heat Recovery Steam generators (HRSGs); one Steam Turbine Generator (STG) and one Utility Boiler (UB) to meet refinery power & steam demand. Design capacities are: GTG of 34 MW each, STG of 12 MW and Utility Boiler of 53TPH. Each GTG has downstream Heat Recovery Steam Generators (HRSG) of each capacity of 130 TPH (with supplementary firing) which recovers heat from the Gas turbine hot exhaust flue gases. In CGP of NRL, Utility Boiler (UB) is one such boiler.Utility Boiler (UB) is a 53 TPH design capacity boiler, natural circulation, water tube, bi-drum, oil and gas fired boiler, supported at bottom. It produces high pressure superheated steam (40.0 kg/cm^2 and 450 deg C). During total power failure situation, it supplies steam for the safe shutdown of the Refinery units for approx. 20 minutes. So it is one of the most critical units of the Refinery. Improving its performance, reliability, flexibility and safety is very important. It too has got different mountings and accessories. Out of such accessories, Flue Gas Recirculation (FGR) is one among them.

Brief Introduction of Flue Gas Recirculation (FGR) fan: FGR is a combustion modification process. As the name implies, a portion of the combustion products exiting the boiler are recirculated and introduced into the primary combustion zone. From this, at least two phenomena occur that reduce the nitrogen oxide (NOx) formation. First, since there is a reduction in the oxygen percent in the flue gases when compared to ambient air, the resulting mixture of air and flue gases will have a reduced percentage of oxygen. Combustion in an atmosphere of reduced oxygen percent helps limit the formation of NOx. Second, because of the increased mass flow through the combustion process, the flame temperature is reduced, also resulting in less NOx formation. Thus the FGR fan contributes towards a safer, greener & more eco-friendly environment by reducing the NOx limit of the flue gas exiting the boiler.

What Environmental Problems form from Nitrogen Oxide Pollution?

- Helps form acid rain
- It contributes to global warming
- It hampers the growth of plants
- NOx can form with other pollutants to form toxic chemicals
- Small levels of NOx can cause nausea, irritated eyes and/or nose, fluid forming in lungs and shortness of breath
- Breathing in high levels of NOx can lead to: rapid, burning spasms; swelling of throat; reduced oxygen intake; a larger build-up of fluids in lungs and/or death

So, it is very important to reduce the NOx formation and keep it under the safe allowable limits of 350mg/Nm3 or 171ppm (in Liquid fuel) and 250mg/Nm3 or 122ppm (in Gaseous fuel).

NB. Here, NOx is a mixture of nitrogen oxides; however, NO2 is of greatest concern and NO oxidizes to NO2 in the atmosphere. Therefore the mixture is treated as NO2. Using integer atomic weights, molar mass is 46 g/mol.

How is NOx produced?

- NOx is produced on chemical reaction between N2 & O2
- This reaction is favorable at high flame peak temperature

How does FGR fan reduce NOx formation in a boiler?

- Lowers the flame peak temperature
- Lowers the oxygen content of combustion air

Thus both NOx favorable conditions are curtailed.

The main advantages of FGR are:

- Saves Fuel thus increasing the Boiler Efficiency and reduces the Boiler Heat rate
- Reduced NOx Emissions
- Increased Steaming Capacity
- Provides potential for increased Boiler flexibility
- Reduction in Peak Flame Temperatures
- Increase in the Boiler back End temperature (i.e., Flue Gas temperature at the exit of the boiler)

FGR fan in CGP Utility Boiler – A case study

- “Arise, awake, and stop not until your goal is achieved.” ---- Swami Vivekananda
- When the world says, "Give up," Hope whispers, "Try it one more time….." --- Author Unknown

The above two great sayings act as a guiding tool to overcome a great obstacle and reach the pinnacle of success.......successful trial run and establishing the permanent service of Utility Boiler Flue Gas Recirculation (FGR) fan. In UB, there are two nos. of FGR fans as shown in the above Fig-1. The FGR fan takes flue gas suction from the flue gas duct just before the stack inlet i.e., after the Economizer section. It’s discharge is mixed with the discharge air of the Forced draught (FD) fan. The mixture of both these is then used for the combustion of the fuel in the furnace. In UB the types of fuels used are Natural Gas (NG)/Refinery Fuel Gas (FG), Naphtha & Industrial Fuel Oil (IFO). Both these FGR fans could not put into service for a long time, in fact since commissioning of the UB. After a series of studies, the following problems were identified. After rectification of these problems, the fans could be run successfully.

The problems which were studied, identified and eventually rectified

Selection of Correct UB load while starting the FGR fan: After a series of experiments and trial and error methods, at various UB loads, it was found that when the FGR fan is started at UB loads lower than 25 TPH, the UB burner flame scanner starts to miss the flame. The flame becomes unstable. The flame unstability is more in the liquid fuel (IFO) than that in Gaseous fuel (natural gas or fuel gas).The flame condition degrades i.e., the flame brightness becomes less. So the flame scanner starts missing the flame. Also there is a sudden fluctuation in the FD fan discharge pressure and furnace pressure. These phenomena in many cases tripped the burner and often leading to tripping of the boiler. But when it was started at load above 25 TPH, this problem is slightly lesser. After some adjustment in the fuel atomizing media and the flue gas oxygen %, the burner flame slowly gets stabilised and thus prevents the burner tripping. Once the flame is stabilised, the FGR fan can be continued without problem. Also the UB load can be slowly lowered up-to 18TPHto 20 TPH. Thus it is seen that the fan is to be started at the UB load of approximately 50% of the design load (53 TPH).

FGR & FD fans dampers adjustment: After series of activities and adjustment of dampers, it is seen that the FGR fan dampers have to be kept as below. On doing this the fan can be successfully started.

Table 1. Shows Net Energy Savings & Monetary Profits in UB after FGR fan in service per day NB. GCal: Gigacalorie

Savings in UB after FGR fan in service					
Steam Load	*FGR in service*	*FGR not in service*	Net Energy saved	Savings/Profit on	Remarks
	Total Energy Consumed	Total Energy Consumed		Equivalent NG saved	UB Burner
MT/day	GCal/day	GCal/day	GCal/day	Rupees/day	Combination
554	312.72	423.29	110.23	146250.93	IFO+NG Combination
594	330.61	435.44	104.50	138647.08	
616	326.07	444.62	118.22	156839.48	
643	375.62	478.94	102.98	136625.60	
661	389.32	509.13	119.47	158508.03	
700	348.11	372.77	24.33	32278.45	
761	391.19	413.77	22.25	29525.58	
769	391.30	450.71	59.08	78378.81	
771	395.34	431.90	36.23	48068.41	
795	413.75	446.18	32.09	42578.31	
725	387.34	398.65	10.97	14556.87	All 4 Burners in NG
742	398.08	404.87	6.45	8556.87	
767	420.09	426.01	5.59	7416.87	

Table 2. Fuel data used

Parameter	HSD	Naphtha	NG	IFO
GCV(kcal/kg)	10210.60	10536.20	11306.00	9980.96
Sp. Gravity	0.85	0.72	0.74	0.92

Table 3. Energy consumed by FGR fan

Energy consumed by FGR fan		
Data :	Avg. current = 25 A	
	Avg. Voltage = 415 V = 0.415 kV	
	pf = cos ø= 0.9	
	1 kCal = 4.184 kJ	
	So, 1 kJ = 0.239 kCal	
	Avg. FGR fan discharge damper opening = 22%	
	Power consumed by FGR fan motor	
	√3*V*I*pf	
	16.17255	kW
	388.1412	kWh
	1397308	kWs or kJ
	333956.7	kCal
	0.333957	GCal
	0.334	GCal

Table 4. Reduction in CO2 emission in UB after FGR fan in service

CO2 Emission reduction UB after FGR fan in service						
UB Steam generation MT/day	Net Energy saved GCal/day	Net Energy saved kCal/day	Equivalent Power generated by GTG kW/day	Equivalent CO2 emission reduced Tonne/day	Equivalent CO2 emission reduced Tonne/year	Remarks UB Burner Combination
554.00	110.23	110234204.26	4460.98	2.24	817.39	IFO+NG Combination
594.00	104.50	104502928.10	4229.05	2.12	774.89	
616.00	118.22	118215147.30	4783.96	2.40	876.56	
643.00	102.98	102979267.99	4167.39	2.09	763.59	
661.00	119.47	119472783.71	4834.85	2.43	885.89	
700.00	24.33	24329347.35	984.57	0.49	180.40	
761.00	22.25	22254416.78	900.60	0.45	165.02	
769.00	59.08	59076722.37	2390.73	1.20	438.05	
771.00	36.23	36230760.33	1466.19	0.74	268.65	
795.00	32.09	32092690.79	1298.73	0.65	237.97	
725.00	10.97	10972000.00	444.02	0.22	81.36	All 4 Burners in NG
742.00	6.45	6449600.00	261.00	0.13	47.82	
767.00	5.59	5590344.00	226.23	0.11	41.45	

Reduction in CO2 emission (NG)		
NG emits 0.502 kg of CO2 per kWh		
CPP GTG-1 NG Consumption after uprate		
Energy in 1 MWh	24710739.27	kCal/h

Table 5. Comparisons of Steam by Fuel Ratio in UB (increase in steaming rate)

Comparisons of Steam by Fuel Ratio in UB					
Sl.No.	UB Steam Load MT/day	With FGR S/F ratio	Without FGR S/F ratio	Increase in S/F ratio with FGR	Remarks UB Burner Combination
1	554	18.56	13.99	4.56	IFO+NG Combination
2	594	18.81	14.58	4.22	
3	616	19.79	14.47	5.32	
4	643	17.85	14.43	3.42	
5	661	17.78	13.88	3.90	
6	700	21.34	20.01	1.33	
7	761	20.78	19.65	1.13	
8	769	21.06	19.06	1.99	
9	771	20.84	18.98	1.86	
10	795	20.55	18.88	1.67	
11	725	21.16	20.56	0.60	All 4 Burners in NG
12	742	21.07	20.72	0.35	
13	767	20.64	20.36	0.29	

Table 6. (i),(ii):UB Flue Gas NOx comparisons

UB Flue Gas NOx					UB Flue Gas NOx			
UB Steam	Flue Gas NOx (ppm)				UB Steam	Flue Gas NOx (ppm)		
TPH	With FGR	Without FGR	NOx reduced		TPH	With FGR	Without FGR	NOx reduced
24	62	94	32		29.5	40.1	58	17.9
25	74	105	31		31	43	61	18
26	83	110	27		33	46	63	17
27	71	112	41		37	57	68	11
30	62	87	25		34	52	70	18
31	63	86	23		39	52	71	19
32	64	88	24		41	58	72	14
33	60	85.1	25.1					
34	61	82.6	21.6		Fuel Combination: 4 NG			
35	63	86.5	23.5		Table-6(ii)			
Fuel Combination: 3 NG + 1 IFO								

Table 7. Rise in Flue Gas backend temperature

Flue Gas back End Temperature in UB			
UB steam load	With FGR	Without FGR	Rise in backend temp
TPH	FG backend temp deg C	FG backend temp deg C	with FGR deg C
24	138.90	131.90	7.00
25	139.73	131.80	7.93
27	137.30	131.60	5.70
29	140.20	136.00	4.20
29.5	142.30	137.50	4.80
30	140.80	136.50	4.30
30.5	142.10	136.50	5.60
31	142.30	138.40	3.90
32	143.50	138.90	4.60
35	142.20	136.70	5.50
Average rise in Flue Gas backend temp			5.35

- Suction header manual isolation valve to about 50% open.
- Pneumatic (Instrument air) operated discharge valve at minimum opening (3% to 5%).
- Once the fan is started, the suction and discharge valves are to be opened slowly such that Forced Draft (FD) fan discharge pr. is about 90 to 120 mm WC & FGR discharge pr. is about 300 to 340 mm WC. The FGR discharge pr. to be kept higher than that of FD fan so that a positive flow of flue gas from FGR could be maintained. Both the FGR and FD fans supply air into the combustion zone.

Problems analysis&Probable causes of burner tripping

- At lower UB loads, FD discharge pressure & combustion air pressures remain on lower side.
- Also, the oxygen % in the flue gas remains on lower side (2.5 to 3%).
- When FGR is started, the O2 further reduces due to sudden increase in air mass flow.
- Already balanced parameters of fuel flow, atomizing, O2 & combustion pressures - disturbed.
- This creates imbalance leads to flame un-stability &it'sflame quality degradation.
- Due to this poor flame quality, the flame scanner misses the flame leading to burner tripping and sometimes eventually to boiler tripping.

Practical advantages achieved in UB after FGR in service

- Increases steaming rate (increase in steam by fuel ratio)
- Saves Energy (Fossil Fuel optimization) & Monetary savings (Profits)

- Reduced NOx Emissions
- Increased in flue gas back end temperature
- Reduced harmful greenhouse gas CO2 emission
- The above advantages are shown in the following subsequent tables:-

Abbreviations used

- NRL – Numaligarh Refinery Limited
- P&U – Power & Utility Department
- CGP – Co-generation Plant
- CPP – Captive Power Plant
- GTG – Gas Turbine Generator
- UB – Utility Boiler
- FGR fan – Flue gas Recirculation fan
- STG – Steam Turbine Generator
- HRSG – Heat Recovery Steam Generator
- FD – Forced Draft
- NOx – Nitrogen Oxides (NO2 is considered)
- IFO – Industrial/Intermittent Fuel Oil
- NG – Natural Gas
- FG – Fuel Gas
- HSD – High Speed Diesel
- GCV – Gross Calorific Value
- S/F ratio – Steam by Fuel ratio
- T – Tonne
- ksc – kg/cm2
- MT – Metric Tonne
- TPH – Tonne Per Hour
- kW – Kilo watt
- MW – Mega Watt
- MWh – Mega Watt hour
- kWh – kilo watt hour
- GCal – Giga Calorie
- kCal – kilo Calorie
- kWs – kilo watt second
- kJ – kilo Joule
- mmWC – millimetreof water column

Conclusion

The continuous efforts coupled with the never say dying attitude and hope against hope helped us to find out the root causes of the problems which were hindering the running of Utility Boiler Flue Gas Recirculation (FGR) fan since the commissioning of the Boiler and which earlier led to the tripping of burners and sometimes tripping of the Boiler. After trouble shooting of all the possible problems and root causes, the FGR fan could be successfully taken trial run and could be put into service permanently which in turn brought about flexibility, efficiency enhancement; and Process and Energy optimization in the operation of the Utility Boiler. It brought about continuous improvement and an excellence in the operation of the Utility Boiler. In addition to that, it also helping in the reduction of the direct harmful greenhouse gas CO2 emission and also reduces the emission of indirect harmful greenhouse gas NOx; thereby resulting in a greener, cleaner and better environment to live in. Thus the great obstacle is overcome and the pinnacle of success is achieved in the operation of the Utility Boiler.

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