-// Appendix II //-

Supporting Details for CEA Recommendations on Part Load Heat Rate & Auxiliary Energy Consumption Degradations and Operation Norms for DeSOx & DeNOx Systems in respect of Thermal Generating Stations

1. **Impact of Part Load Operation on Station Heat Rate of Coal/ Lignite Based Thermal Generating Stations:**

A thermal unit is designed for optimum heat rate at rated full load i.e. 100% MCR. At part load, performance deteriorates and heat rate increases depending upon deviation from design condition and plant operating practices. Because of increasing impact of renewables and for other considerations, thermal power plants often are required to operate at reduced loading. In order to account for increased station heat rate due to part loading, CERC, vide its notification dated 6.4.2016, has provided the following station heat rate degradation factors for coal/ lignite based generating stations as compensation for part loading of the units:

Sl. No.	Unit loading as % of installed capacity of the unit	Increase in station heat rate (%)	
		Sub- critical units	Super- critical units
1.	85- 100	Nil	Nil
2.	75 - 84.99	2.25	1.25
3.	65 - 74.99	4	2
4.	55 - 64.99	6	3

As per above table, no degradation is admissible upto 85% loading and first admissible step for sub- critical units is of 2.25% which is equal to half of admissible operation margin of 4.5%. This appears to be too steep and appreciable degradation in the load range above 85% is not addressed.

The turbine cycle heat rate degradation at part load as per OEM's HBDs for some sub- critical and super- critical thermal units as available at specific unit loading (viz. 100%, 80%, 60%, 50%, 40%) has been analysed. In this respect, the heat rate values at specified unit loading have been calculated from the HBDs and the values at intermediate loading have been taken as per appropriate curve fitting. The expected trend of heat rate degradation at part load is indicated below:

<u>Sub- critical units:</u>

Unit loading	Turbine Cycle Heat Rate Degradation				Average Heat Rate degradation (%)
	500MW (Vindhyachal TPS)*		250MW (Bongaigaon TPS)*		
	Heat rate (Kcal/kWh)	Heat rate degradation (%)	Heat rate (Kcal/kWh)	Heat rate degradation (%)	

100%	1931.6	Base	1943.7	Base	Base
95%	1937.4	0.30	1958.9	0.79	0.54
90%	1945.3	0.71	1971.3	1.42	1.06
85%	1956.3	1.28	1982.6	2.00	1.64
80%	1974.6	2.23	1994.3	2.605	2.42
75%	1987.5	2.89	2008.6	3.34	3.12
70%	2007.7	3.94	2026.5	4.26	4.10
65%	2031.1	5.15	2049.7	5.46	5.30
60%	2051.4	6.20	2079.7	7.00	6.60
55%	2087.0	8.04	2118.4	8.99	8.52
50%	2123.0	9.91	2167.0	11.49	10.70
45%	2155.3	11.58	2203.8	13.38	12.48
40%	2194.1	13.59	2249.4	15.73	14.66

* HBDs available for 100%, 80%, 60% & 50%.

Super- critical units:

Unit loading (%)	Turbine Cycle Heat Rate Degradation						Average Heat Rate increase (%)
	660MW (Solapur TPS)*		660MW (Talwandi Sabo TPS)**		800MW (Telangana TPS)*		
	Heat rate (Kcal/kWh)	Heat rate degradation (%)	Heat rate (Kcal/kWh)	Heat rate degradation (%)	Heat rate (Kcal/kWh)	Heat rate degradation (%)	
100	1832.2	Base	1906.7	Base	1776.0	Base	Base
95	1835.9	0.20	1908.7	0.11	1782.8	0.38	0.23
90	1841.4	0.50	1912.4	0.30	1790.2	0.80	0.53
85	1848.8	0.91	1919.2	0.65	1799.4	1.32	0.96
80	1858.5	1.44	1933.6	1.41	1812.3	2.05	1.63
75	1868.9	2.01	1942.1	1.86	1822.8	2.64	2.17
70	1881.8	2.71	1958.2	2.70	1837.2	3.45	2.95
65	1896.4	3.51	1977.4	3.71	1853.2	4.35	3.86
60	1912.2	4.37	1995.3	4.65	1867.3	5.14	4.72
55	1931.3	5.41	2025.3	6.22	1890.5	6.45	6.03

50	1951.9	6.53	2053.9	7.72	1913.5	7.74	7.33
45	1973.5	7.71	2085.5	9.38	1934.7	8.94	8.68
40	1997.3	9.02	2121.9	11.29	1959.4	10.33	10.21

* HBDs available for 100%, 80%, 60% & 50%.

** HBDs available for 100%, 80%, 60% & 40%.

The HBDs for 500MW unit at Vindhyachal TPS, 250MW unit at Bongaigaon TPS, 660MW unit at Solapur TPS, 660MW unit at Talwandi Sabo TPS and 800MW unit at Telangana TPS are enclosed as **Appendix-1.**

There is no significant change in boiler efficiency at part loading. As such, turbine cycle heat rate degradation in % can be taken as applicable for degradation of the unit heat rate also. As per analysis of plant operation data carried out in this report for 5 year period, it is observed that actual degradation observed is less than as expected also which may be due to better operational measures adopted in actual operation. Based on expected degradation as per HBDs, observed actual part load performance degradation, and application of part load correction in more reasonable steps, the increase of unit heat rate for coal/ lignite based sub- critical & super-critical units is proposed to be appropriately considered as per the following:

Unit HR degradation (%)		
Unit loading (%)	**Sub- critical units**	**Super- critical units**
90 – 100	**0**	**0**
80 - 89.99	**1.3**	**0.9**
70 - 79.99	**2.8**	**2.1**
60 - 69.99	**4.8**	**3.7**
50 - 59.99	**7.2**	**5.7**
40 - 49.99	**10.0**	**8.0**

2. Impact of Part Load Operation on Auxiliary Energy Consumption Station of Coal/ Lignite Based Thermal Generating Stations:

CERC, vide its notification dated 6.4.2016, has provided the following auxiliary energy degradation factors for coal/ lignite based generating stations as compensation for part loading of the units:

Sl. No.	Unit loading as % of installed capacity of the unit	% degradation in auxiliary energy consumption admissible
1.	85- 100	Nil

2.	75 - 84.99	0.36
3.	65 - 74.99	0.65
4.	55 - 64.99	1.00

The above additional auxiliary energy consumption values have been reviewed so as to have application steps similar to that proposed for application of station heat rate correction. In this respect, no OEM data is available for coal/ lignite based stations. However, to revise the correction steps for application from 90% loading level, comparison of CERC values (considered at mid- point of the range) has been made with AEC degradation data/ curve of OEM (BHEL) available for Bawana CCPP and same is indicated below:

Load (%)	Bawana CCPP (685.6 MW)		Additional AEC as per CERC values (mid-point of the applicable load range) (% point)	Additional AEC values considered for revised load ranges (% point)
	AEC as per OEM curve (%)	Additional AEC (% point)		
100	2.55	Base	Base	Base
95	2.63	0.08	--	--
90	2.71	0.16	--	--
85	2.80	0.25	--	0.25
80	2.90	0.35	0.36	--
75	3.05	0.50	--	0.50
70	3.20	0.65	0.65	--
65	3.35	0.80	--	0.80
60	3.55	1.00	1.0	--
55	3.75	1.20	--	1.20
50	4.00	1.45	--	--
45	4.35	1.80	--	1.80
40	4.90	2.35	--	

The AEC degradation curve of BHEL for 685.6 MW Bawana CCPP is enclosed as **Appendix- 2.**

It is observed that CERC values for additional AEC for coal/ lignite based stations at 3 loading levels are similar to those as per BHEL curve for 685.6 MW Bawana CCPP at same loading levels. Based on this similarity and also keeping in view the observed part load performance of the stations, the suggested AEC correction values with application steps similar to that proposed for application of station heat rate (i.e. from level of 90% loading) are indicated as below:

Sl. No.	Unit/ plant loading as % of installed capacity	Admissible % degradation in auxiliary energy consumption (% point)
1.	**90 to 100**	**Nil**
2.	**80 to 89.99**	**0.25**
3.	**70 to 79.99**	**0.50**
4.	**60 to 69.99**	**0.80**
5.	**50 to 59.99**	**1.20**
6.	**40 to 49.99**	**1.80**

3. **Impact of Part Load Operation on Station Heat Rate of Gas/ Liquid Fuel Based Thermal Generating Stations:**

It is understood that presently there is no specific norm for station heat rate degradation factors for gas/ liquid fuel based generating stations as compensation for part loading. Further, in case of gas/ liquid fuel based units, there are, in general, more than one mode of plant operation depending upon level of operating load and availability of machines of the module. For example, for a CCGT module of (2GT+ST) module, there are three (3) possible modes of operation i.e. (2GT+ ST) mode, (1GT+ST) mode and GT in open cycle mode. All these three modes have distinctly different operating heat rates. As such, evaluation of heat rate degradation factor for CCGT modules need to have consideration of individual operation in different modes. Reference OEM data for such evaluation is not available.

The degradation of station heat rate in case of gas/ liquid fuel based generating stations has been analysed based on BHEL curve furnished by M/s PPCL for Bawana CCPP, data furnished by NTPC for their CCPPs and observed actual degradation as per plant operation data analysis for 5 year period. It is also to mention that all the gas/ liquid fuel based stations for which data has been furnished are of combined cycle configuration. The reference input data considered for analysis of heat rate degradation at part load operation of gas/ liquid fuel based stations in CCGT mode is indicted below:

Unit loading (%)	Module Heat Rate Degradation in CCGT Mode						Average Heat Rate increase (%)
	685.6 MW (2x216 MW GT +253.6MW ST) Bawana CCPP		419.33 MW (3x88.71MW GT +153.2MW ST) Anta CCPP		359.8 MW (2x115.2MW GT +129.18MW ST) Kayamkulam CCPP		
	CCGT	CCGT Heat	CCGT	CCGT Heat	CCGT	CCGT Heat	

	Heat rate (Kcal/kWh)	rate degradation (%)	Heat rate (Kcal/kWh)	rate degradation (%)	Heat rate (Kcal/kWh)	rate degradation (%)	
100	1796	Base	1951	Base	1896	Base	Base
95	1802	0.37	--	--	--	--	**0.37**
90	1827	1.74	--	--	--	--	**1.74**
85	1852	3.12	1995	2.26	1962	3.48	**2.95**
80	1877	4.50	2006	2.82	1978	4.32	**3.88**
75	1914	6.56	2034	4.25	2006	5.80	**5.54**
70	1957	8.98	2070	6.10	2026	6.86	**7.31**
65	2012	12.03	2107	8.00	2064	8.86	**9.63**
60	2073	15.41	2153	10.35	2093	10.39	**12.05**
55	2136	18.92	2193	12.40	2125	12.08	**14.47**
50	2199	22.46	--	--	--	--	--

The heat rate degradation curve of BHEL for 685.6 MW Bawana CCPP and heat rate degradation data furnished by NTPC for their CCPPs are enclosed as **Appendix- 3 & 4** respectively.

Based on expected degradation as per above, observed actual part load performance, and application of part load correction in reasonable steps, the increase of unit heat rate for gas/ liquid fuel based stations in CCGT mode is proposed to be appropriately considered as per the following:

Sl. No.	**Module/ plant loading as % of installed capacity**	**Increase in station heat rate (%)**
1.	**90 to 100**	**Nil**
2.	**80 to 89.99**	**2.5**
3.	**70 to 79.99**	**5**
4.	**60 to 69.99**	**8**
5.	**50 to 59.99**	**12**

4. **Impact of Part Load Operation on Auxiliary Energy Consumption of Gas/ Liquid Fuel Based Thermal Generating Stations:**

It is understood that presently there is no specific norm for auxiliary energy degradation factors/ additional admissible auxiliary energy consumption for gas/ liquid fuel based generating stations. The degradation of AEC in case of gas/ liquid fuel based generating stations has been analysed based on BHEL curve furnished by M/s PPCL for Bawana CCPP and data furnished by NTPC for their CCPPs. The reference input data considered for analysis of AEC degradation at part load operation of gas/ liquid fuel based stations in CCGT mode is indicted below. The NTPC data, furnished for load range 85% to 55%, has been adjusted for correction of base to 100% load in line with trend observed for Bawana CCPP.

Unit loading (%)	Module AEC (%) & Additional AEC at Part load in CCGT Mode (% point)								Average Additional AEC (% point)
	685.6 MW (2x216 MW GT + 253.6MW ST) Bawana CCPP		431.586 MW (2x137.758 MW GT + 156.07MW ST) Faridabad CCPP			328.1 MW (2x106MW GT +116.1MW ST) Kawas CCPP			
	AEC as per OEM curve (%)	Additional AEC (% point)	AEC as per NTPC data (%)	*Extrapolated/ adjusted AEC (%)	Adjusted additional AEC (% point)	AEC as per NTPC data (%)	*Extrapolated/ adjusted AEC (%)	Adjusted additional AEC (% point)	
100	2.55	Base	--	2.02	Base	--	1.87	Base	Base
95	2.63	0.08	--	2.12	0.10	--	1.97	0.10	**0.10**
90	2.71	0.16	--	2.23	0.21	--	2.08	0.21	**0.19**
85	2.80	0.25	2.35	2.35	0.33	2.20	2.20	0.33	**0.30**
80	2.90	0.35	2.48	2.48	0.46	2.33	2.33	0.46	**0.42**
75	3.05	0.50	2.62	2.62	0.60	2.55	2.55	0.67	**0.59**
70	3.20	0.65	2.73	2.73	0.71	2.83	2.83	0.96	**0.77**
65	3.35	0.80	2.86	2.86	0.84	3.17	3.17	1.30	**0.98**
60	3.55	1.00	2.97	2.97	0.95	3.48	3.48	1.61	**1.18**
55	3.75	1.20	3.11	3.11	1.09	3.77	3.77	1.90	**1.39**
50	4.00	1.45	--	--	--	--	--	--	**1.45**

* Adjustment for base correction done in line with Bawana CCPP data.

The AEC degradation curve of BHEL for 685.6 MW Bawana CCPP as also referred under item 2 above is enclosed as **Appendix- 2** and AEC degradation data furnished by NTPC for their CCPPs indicated in **Appendix-4** also referred under item 3 above.

Based on expected degradation as per above, observed actual part load performance over 5 year period, and application of part load correction in better loading steps, the increase in AEC for gas/ liquid fuel based stations in CCGT mode is proposed to be appropriately considered as per the following:

Sl. No.	Module/ plant loading as % of installed capacity	Admissible % degradation in auxiliary energy consumption (% point)
1.	90 to 100	Nil
2.	80 to 89.99	0.25
3.	70 to 79.99	0.50
4.	60 to 69.99	0.80
5.	50 to 59.99	1.20

5. Additional operation norm for implementation of DeSOx system in thermal power stations

As per MoEF&CC notification dated 7.12.2015, thermal power stations are required to be provided with DeSOx systems for control of SO_2 emission and meet the following SO_2 emission limits:

Units installed upto 31.12. 2016	: 600 mg/Nm^3 for units < 500MW capacity
	: 200 mg/Nm^3 for units ≥ 500MW capacity
Units installed from 1.1. 2017	: 100 mg/Nm^3

Presently, no relevant operational data is available on DeSOx systems in the country and these systems are under implementation. The following operation norms are worked out based on inputs received from utilities, OEMs and issues as analysed at our end:

i) Limestone consumption of wet limestone based FGD system:

Wet limestone type FGD system is most widely used FGD system for removal of SO_2 from flue gases in thermal power plants. The consumption of limestone depends upon a number of factors including gross station heat rate (SHR), GCV & sulphur content of coal, SO_2 conversion factor, required SO_2 removal efficiency, stoichiometric ratio, purity of limestone etc. For estimating specific limestone consumption, the following assumptions have been made:

- Required SO_2 removal efficiency for emission norm of 100 & 200 mg/Nm^3 = 96%
- Required SO_2 removal efficiency for emission norm of 600 mg/Nm^3 = 73%
- SO_2 conversion factor = 95%
- Stoichiometric molar ratio of reagent consumption= 1.05
- Typical purity of limestone = 85%
- Further, contribution of specific oil consumption in heat rate is neglected.

Based on above assumption, the consumption of 85% purity limestone for wet limestone FGD system has been estimated and same on gross generation basis can be taken as below:

Specific consumption of limestone =

$$\frac{\text{K x Normative heat rate (kcal/kWh) x Sulphur content of coal (\%)}}{\text{GCV of coal (kcal/kg)}} \text{ g/kWh}$$

Where,

K= 35.2 for units to comply with SO_2 emission norm of 100/ 200 mg/Nm^3.

= 26.8 for units to comply with SO_2 emission norm of 600 mg/Nm^3.

The table below indicates comparison of specific limestone consumption based on data furnished by the utilities/ OEM pertaining to wet limestone FGD plants under implementation and that estimated from above empirical formulae.

		Telengana, NTPC	Jhajjar, NTPC	Lara, NTPC	Harduaganj, TJPS	Typical, GE
Plant capacity	MW	2 x 800	3 x 500	2 x 800	1 x 660	2 x 500
Take normative gross heat rate	kcal/kWh	2250	2375	2250	2250	2375
GCV of coal	kcal/kg	3000	3200	3000	3200	3600
Sulphur content of coal	%	0.6	0.5	0.5	0.45	0.5
SO2 removal efficiency	%	97.1	95.1	96.6	95	92
Limestone consumption for one unit	t/h	12245*	7290*	10000*	7200**	5100#
Specific limestone consumption	g/kWh	15.3	14.6	12.5	10.9	10.2
Specific limestone consumption worked out as per proposed formulation	g/kWh	15.8	13.1	13.2	11.1	11.6

*Limestone purity 79% for design & 89% for guarantee.

** Limestone purity 85%.

#Limestone purity 100%.

The data received on DeSOx system from NTPC for their various stations is enclosed as **Appendix- 5**.

From above, good agreement is seen in the indicated limestone consumption and that worked out as per proposed formulae. As such, proposed empirical formulae can be used to calculate admissible limestone consumption of FGD system in thermal power stations.

As such, for units provided with wet limestone based FGD system for control of SO_2 emission, the admissible specific consumption of limestone on gross generation basis is proposed to be taken as per following:

Specific limestone consumption =

$$\frac{\underline{\text{K x Normative heat rate (kcal/kWh) x Sulphur content of coal (\%)}}}{\text{GCV of coal (kcal/kg)}} \text{ g/kWh}$$

Where,

K= 35.2 for units to comply with SO_2 emission norm of 100/ 200 mg/Nm^3.

= 26.8 for units to comply with SO_2 emission norm of 600 mg/Nm^3.

ii) **Lime consumption of lime spray dryer/ semi dry FGD system:**

The lime spray dryer/ semi dry FGD system is generally used for small size units. The efficiency of reagent utilisation in semi dry system is less as compared to that in wet FGD system. The chemical reaction taking place in lime spray dryer/ semi dry FGD system is indicated as below:

$CaO + H_2O = Ca(OH)_2$

(1x56)

$Ca(OH)_2 + SO_2 + 1/2\ O_2 = CaSO_4 + H_2O$

(1x64)

As per the chemical reaction between lime and SO_2, one mole of Ca is stoichiometrically required to neutralise one mole of SO_2. For lime spray dryer system, the reagent feed ratio is generally expressed in terms of mole Ca/mole of SO_2 in the inlet flue gas. The reagent feed ratio varies considerably with required efficiency of SO_2 removal. It varies from the order of 0.9 mole Ca/mole of input SO_2 for around 70% removal efficiency to the order of 1.6 mole Ca/mole of input SO_2 for around 90% removal efficiency. These feed ratios are equivalent to 1.3 mole Ca/mole of SO_2 removed for around 70% removal efficiency range and 1.8 mole Ca/mole of SO_2 removal for 90% efficiency range.

For units to comply with SO_2 emission limit of 600 mg/Nm3, typical required SO_2 removal efficiency is expected to be of the order of 70%. For such cases, the lime spray dryer/ semi dry FGD system using lime provides a feasible option with reagent requirement appropriately taken as 1.35 mole of Ca per mole of SO_2 removed. The extract of M/s Sargent & Lundy reference document available on internet is enclosed as **Appendix- 6**.

For a typical 210 MW series unit, the specific consumption of lime is estimated as below:

Take normative heat rate of the unit = 2450 kcal/kWh

Take GCV of coal= 3600 kcal/kg

Sulphur content = 0.5%

SO_2 conversion factor = 95%

Expected SO_2 level in flue gas = 1800 mg/Nm3

Considering SO_2 level in exit flue gas as 550- 600 mg/Nm3, the required capture efficiency shall be of the order of 70%.

Take typical purity of lime = 90%

For above inputs, the requirement of lime

= (2450/3600)*(0.5/100)*0.95*(64/32)*0.7*(1.35*56/64)*1000/0.90

= 5.94 g/kWh

Say 6 g/kWh

In the data furnished by OEM, the requirement of 100% lime for lime spray dryer/ semi dry FGD system in a typical 2x210 MW plant for SO_2 removal efficiency of 70% has been indicated as 2300 kg/h. This amounts to specific consumption of 100% purity lime as 5.48 g/kWh and 90% purity lime as 6.08 g/kWh.

As such, for units to comply with SO_2 emission norm of 600 mg/ Nm^3 and provided with lime spray dryer/ semi dry FGD system, the admissible **specific consumption of 90% purity lime (CaO) on gross generation basis is proposed to be taken as 6 g/kWh**.

iii) **Sodium bicarbonate consumption of dry sorbent injection system:**

The dry sorbent injection system using sodium bicarbonate is generally used for small size units with low SO_2 removal requirements. The efficiency of reagent utilisation in dry sorbent injection system is less as compared to that in wet FGD and semi dry FGD systems. The system has lower capital cost and smaller construction time but higher reagent cost.

The chemical reaction taking place in dry sorbent system is indicated as below:

$2\ NaHCO_3 + Heat = Na_2CO_3 + H_2O + CO_2$
(2x84)
$Na_2CO_3 + SO_2 = Na_2SO_4 + CO_2$
(1x64)

As per above, theoretically, 2 moles of $NaHCO_3$ are required to remove 1 mole of SO_2. In case of DSI, the requirement of reagent is expressed in terms of normalised stoichiometric ration (NSR) defined as moles of Na_2 required per mole of inlet SO_2 and depends considerably with required SO_2 removal efficiency. It varies from the order of 0.5 for around 30% SO_2 removal efficiency to the order of 2.0 for around 70% removal efficiency. The NSR value of 1.0 can be considered for SO_2 removal efficiency of about 50%. The extract of a reference document on the same as available on internet is enclosed as **Appendix- 7**.

For units to comply with SO_2 emission limit of 600 mg/Nm^3 and coal having low sulphur content, the required SO_2 removal efficiency is expected to be of the order of 50- 55%. For such cases, the dry sorbent injection system using sodium bicarbonate makes a feasible option and NRS of 1.0 can be taken as an appropriate value for the same. For a typical 210 MW series unit, the specific consumption of sodium bicarbonate is estimated as below:

Take normative heat rate of the unit = 2450 kcal/kWh

Take GCV of coal= 3600 kcal/kg

Sulphur content = 0.35%

SO_2 conversion factor = 95%

Expected SO_2 level in flue gas = 1200 mg/Nm^3

Considering SO_2 level in exit flue gas as 550- 600 mg/Nm^3, the required capture efficiency shall be of the order of 50%.

For above inputs, the requirement of 100% pure sodium bi-carbonate

= (2450/3600)*(0.35/100)*0.95*(64/32)*(2.0*84/64)*1000

= 12 g/kWh

In the data furnished by NTPC, the requirement of 99% sodium bi- carbonate for DSI being considered for 210 MW unit at Dadri is indicated as 2180 kg/h. This amounts to specific consumption of 10.4 g/kWh.

As such, for units to comply with SO_2 emission norm of 600 mg/ Nm^3 and provided with dry sorbent injection system, the admissible **normative specific consumption of 100% purity sodium bi- carbonate on gross generation basis is proposed to be taken as 12 g/kWh**.

iv) **Limestone consumption for furnace injection in CFBC power plant:**

In CFBC power plants, limestone is in- situ injected into the boiler furnace along with fuel (lignite) for control of SO_2. The efficiency of reagent utilisation in CFBC is less as compared to that in FGD system. The chemical reaction taking place in furnace injection of limestone for control of SO_2 in CFBC boiler is indicated as below:

$CaCO_3$ + heat = CaO + CO_2
(1x100)
$CaO + SO_2 + 1/2\ O_2 = CaSO_4$
(1x64)

As per the chemical reaction between lime and SO_2, one mole of Ca is stoichiometrically required to neutralise one mole of SO_2. For furnace injection of limestone, the reagent feed ratio is generally expressed in terms of mole Ca/mole of SO_2 generated. The reagent feed ratio varies considerably with required efficiency of SO_2 removal. Typically, CFBC can achieve a sulphur removal efficiency of the order of 90- 95% at a Ca/S molar ratio of around 2. Furnace injection of limestone is able to reduce SO_2 level in exit flue gas upto the level of 200- 300 mg/Nm^3.

For CFBC units to comply with SO_2 emission limit of 600 mg/Nm^3, typical required SO_2 removal efficiency can be upto the level of 90% depending upon level of SOx generation in the boiler. For the purpose of norm, limestone consumption is considered to be calculated taking appropriate value of Ca/S molar ratio as 1.8. In this reference, the extract of a reference paper available on internet is also enclosed as **Appendix- 8**.

Based on above assumption, the consumption of 85% purity limestone can be taken as below:

Specific consumption of limestone =

$$\frac{62.9 \text{ x Normative heat rate (kcal/kWh) x Sulphur content of coal (\%)}}{\text{GCV of coal (kcal/kg)}} \text{ g/kWh}$$

For example:

For a lignite based CFBC unit having normative station heat rate of 2500 kcal/kWh, GCV of lignite as 2650 kcal/kg with sulphur content as 0.7 %, the admissible amount of limestone consumption for the unit on gross generation basis for compliance of SO_2 emission norm of 600 mg/ Nm^3 shall be:

= 62.9 x 2500 x 0.7)/2650 = 41.5 g/kWh (59.3 g/kWh for 1 % sulphur)

In the data furnished by NLCIL, consumption of 85% purity limestone for one 250 MW unit of TPS- II Exp. has been indicated as 15000 kg/h with GCV of lignite as 2650 kcal/kg and sulphur content as 0.7 % for best quality lignite and 1 % for worst quality lignite. The indicated consumption amounts to 60 g/kWh which compares well with the specific limestone consumption admissible as per proposed formulation. The data furnished by M/s NLCIL is enclosed as **Appendix- 9**.

It is also to mention that in the notification dated 24.2.2014 of Rajasthan Electricity Regulatory Commission (RERC), the regulation 45(5) indicates for normative limestone consumption of lignite based CFBC power plant to be computed in the following manner:

Limestone consumption = 0.056 x normative specific lignite consumption (kg/kWh) x S_{avg} (%) kg/kWh

Where, S_{avg} = weighted average inorganic sulphur content in lignite.

It is to mention that in the above formulation, the purity of limestone has not been indicated/ referred. The extract of RERC notification dated 24.2.2014 is enclosed as **Appendix- 10**.

v) **Auxiliary energy consumption of FGD system:**

a) Wet limestone based FGD system:

In the operation data furnished to CEA, no data has been indicated on actual AEC of FGD system. In respect of limestone based FGD system for Vindhyachal Stage- V TPS (1x500MW), NTPC has indicated for AEC of 5.8 MW at full load of the station which amounts to 1.16% of gross generation. Further, FGD system is indicated to be provided with GGH and booster fans.

As per the data collected from utilities, the wet limestone based FGDs under implementation/ bidding are mostly envisaged without provision of GGH. NTPC has indicated the auxiliary energy consumption values in a range (Appendix- 5). Based on the values furnished, the normative auxiliary energy consumption for wet limestone FGD (without GGH) is proposed to be taken as 1% of gross generation of the power plant.

b) Sea water based FGD system:

Sea water based FGD is applicable for coastal locations. The auxiliary energy consumption for sea water based FGD is generally less than that for wet limestone based FGD. For power stations based on sea water once- through CW system, the auxiliary energy consumption of FGD system is proposed to be considered as 0.7% of gross output of the power plant (vis- a vis 1% considered for wet limestone based FGD system) without consideration of GGH.

[The auxiliary energy consumption of sea water based FGD system indicated as 1% in CEA recommendations furnished vide letter dated 20.2.2019 may be taken as revised to 0.7% (without GGH).]

c) Lime spray dryer/ semi dry FGD system:

Based on data furnished by OEM for typical lime spray dryer/ semi dry FGD system, the auxiliary energy consumption of lime spray dryer/ semi dry FGD system is proposed to be considered as 1% of gross generation of the power plant.

d) Dry Sorbent Injection (DSI) System:

Auxiliary energy consumption in Dry Sorbent Injection system due to milling & pneumatic conveying of reagent is considered to be insignificant as compared to total auxiliary energy consumption of the power plant/ unit.

e) Additional auxiliary energy consumption for provision of GGH:

For FGD envisaged with GGH, additional auxiliary energy consumption is proposed to be taken as 0.3% of gross generation of the power plant/ unit.

6. Additional operation norm for implementation of DeNOx system in thermal power stations

As per MoEF&CC notification dated 7.12.2015, thermal power stations are required to be provided with DeNOx system for control of NOx emission and meet the following NOx emission limits:

Units installed upto 31.12. 2003 : 600 mg/Nm^3

Units installed after 1.1. 2004 up to 31.12. 2016 : 300 mg/Nm^3

Units installed from 1.1. 2017 : 100 mg/Nm^3

The NOx generation in pulverised coal power plant boilers is generally considered as 260 g/GJ of heat input in the boiler and this corresponds to the NOx level of about 750 mg/Nm^3 in the flue gas. Primary means of combustion modification are able to reduce NOx emission level upto 450 mg/Nm^3. As such, primary means of combustion modification are adequate for power plants to comply with NOx emission limit of 600 mg/Nm3. For emission reduction below about 450 mg/Nm^3 level, SCR/ SNCR system need to be adopted. SNCR is considered for plants to comply with NOx emission limit of 300 mg/Nm^3 and SCR for plants to comply with NOx emission limit of 100 mg/Nm^3. The NOx produced in the boiler comprises of about 95% as NO, however, it is reported in NO_2.

Generally, urea $[(NH_2)_2CO]$ is used as reagent in SNCR and ammonia (NH_3) in SCR for control of NOx emission from the boiler.

The chemical reaction taking place with use of ammonia and urea are indicated as below:

$2\ NH_3 + 2\ NO + \frac{1}{2}\ O_2 = 2\ N_2 + 3\ H_2O$
(2x17) (2x30)

$(NH_2)_2CO + 2\ NO + \frac{1}{2}\ O_2 = 2\ N_2 + 2\ H_2O + CO_2$
(1x60) (2x30)

In the reactions taking place, the NO_x is represented as NO since it is the predominant form of NO_x within the boiler. Theoretically, 1 mole of ammonia (or ½ mole of urea) is required to remove 1 mole of NOx.

The NOx reduction reactions are most effective within a specified temperature range or window. Factors such as the temperature, residence time, reagent distribution in the flue gas etc. have impact on performance of NOx reduction.

Presently, no DeNOx systems have been installed in the country and operational data is available on the same. Presently, pilot studies are underway for suitability of DeNOx systems for high ash Indian coals. The following operation norms are worked out based on inputs received from utilities, OEMs and issues as analysed at our end.

i) Reagent consumption for plants using SNCR to comply with NOx emission limit of 300 mg/Nm^3

In case of SNCR, the actual requirement of reagent is expressed in terms of normalised stoichiometric ration (NSR), defined as moles of ammonia required per mole of inlet NOx and varies considerably depending upon inlet NOx concentration and required NOx removal efficiency. The extract of EPA document No. EPA/452/B-02-001 (Section- 4, NOx controls) is enclosed as **Appendix- 11**.

For plants with permissible emission limit of 300 mg/Nm^3, take NOx reduction to be achieved from inlet level of 450 mg/Nm^3 = 150- 175 mg/Nm^3 [considering a margin of 25 mg/Nm^3]

Required NOx reduction efficiency range = 30- 40%.

For 30- 40 % NOx reduction in SNCR, take appropriate value of NSR as 1.1.

Take normative unit heat rate of a typical 500 MW unit = 2375 kcal/kWh
NOx generation as per heat rate of the unit = 2.585 g/kWh (based on 260 g/GJ)
(This is considered to be corresponding to NOx concentration of 750 mg/Nm^3)

On pro- rata basis, NOx for concentration of 450 mg/Nm^3 = 1.551 g/kWh

Requirement of 100% urea= (0.5x60/46) x 1.1 x 1.551= 1.113 g/kWh
Say 1.2 g/kWh

In the data furnished by OEM, the requirement of 100% urea for SNCR in a typical 500 MW unit for NOx reduction from level of 450 to 175 mg/Nm^3 has been indicated as 500 kg/h. This amounts to specific consumption of 1.0 g/kWh and compares well with the norm worked out above.

As such, for units to comply with NOx emission norm of 300 mg/ Nm^3 and provided with SNCR system, the admissible **specific consumption of 100% pure urea on gross generation basis is proposed to be taken as 1.2 g/kWh**.

ii) Reagent consumption for plants using SCR to comply with NOx emission limit of 100 mg/Nm^3

For plants with permissible emission limit of 100 mg/Nm^3, take NOx reduction to be achieved = 350- 375 mg/Nm^3 [considering a margin of 25 mg/Nm^3]
Required NOx reduction efficiency range = 75- 85%.

In case of SCR, the actual requirement of reagent is expressed in terms of stoichiometric ration (SR), defined as moles of ammonia required per mole of NOx removed. For estimating reagent consumption for 75- 85 % NOx reduction in SCR, take appropriate value of stoichiometric ration (SR) as 1.08. The extract of a paper by M. Nahavandi on SCR system for NOx reduction as available on internet is enclosed as **Appendix- 12**.

Take normative unit heat rate of 660 MW unit = 2250 kcal/kWh

NOx generation as per heat rate of the unit = 2.449 g/kWh (based on 260 g/GJ)
(This is considered to be corresponding to concentration of 750 mg/Nm^3)

On pro- rata basis, NOx for concentration of 450 mg/Nm^3 = 1.469 g/kWh

NOx removal to achieve emission level of 75 mg/Nm3 = 375 mg/Nm3 = 1.225 g/kWh

Requirement of 100% ammonia = (17/46) x 1.08 x 1.225= 0.489 g/kWh
Say 0.5 g/kWh

In the data furnished by OEM, the requirement of 100% ammonia for SCR in 1x660 MW Harduaganj TPS for NOx reduction from level of 406 to 81 mg/Nm3 has been indicated as 286 kg/h. This amounts to specific ammonia consumption of 0.433 g/kWh and compares well with the norm worked out above.

As such, for units to comply with NOx emission norm of 100 mg/ Nm^3 and provided with SCR system, the admissible **specific consumption of 100% ammonia on gross generation basis is proposed to be taken as 0.5 g/kWh**.

[The specific consumption of 100% ammonia on gross generation basis for SCR system indicated as 0.6 g/kWh in CEA recommendations furnished vide letter dated 20.2.2019 may be taken as revised to 0.5 g/kWh.]

iii) Additional auxiliary energy consumption for plants using SCR to comply with NOx emission limit of 100 mg/Nm^3

The catalyst sections of SCR system are required to be installed in the flue gas path between economiser and air preheaters. The pressure drop on account of this results in requirement of additional auxiliary energy consumption by ID fans. As per data received from OEMs, the pressure drop of SCR system in a 660 MW unit amounts to about 150 mmwc and average additional power consumption is indicated about 1.3 MW. For the purpose of the norm, the additional auxiliary energy consumption on account of SCR system is suggested to be taken as 0.2% of gross output.

The above operation norms for reagent consumption and auxiliary energy consumption in respect of DeSOx systems and DeNOx systems may be further reviewed by CERC at their end and these are also suggested to be reviewed after sufficient operational data is available in due course of time.

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