भारत सरकार / Government of India
विद्युत मंत्रालय / Ministry of Power
केंद्रिय विद्युत प्राधिकरण / Central Electricity Authority
तापीय यांत्रिकी एवं अभियांत्रिकी विकास प्रभाग
Thermal Engineering & Technology Development Division

संख्या: CEA/TETD-TT/2019/N-15/266 दिनांक : 20.02.2019

सेवा में

सचिव,
केंद्रीय विधुत विनियामक आयोग,
तीसरी और चौथी मंजिल,
चंद्रलोक बिल्डिंग, 36, जनपथ,
नई दिल्ली - 110 001

विषय: CERC Terms and Conditions of Tariff for the tariff period starting from 01.04.2019 – CEA Recommendations on Operation Norms for thermal generating stations - के बारे में.

महोदय,

In continuation to CEA recommendations on Operation Norms for Thermal Generating Stations for the Tariff Period 2019- 24 forwarded vide our letter No. CEA/TETD-TT/2018/N-15/1451-1454 dated 10.12.2018, CEA recommendations on additional operation norms pertaining to implementation of new environmental emission control measures in thermal power stations are enclosed herewith as Annexure-1.

This issues with the approval of Chairperson, CEA.

संलग्नक: यथोपरी.

भवदीय,

चप्रजैन 20.2.2019

(चंद्र प्रभु जैन)
निदेशक

Copy for kind information to: i) अध्यक्ष, के.वि.प्रा.
ii) सदस्य (तापीय), के.वि.प्रा.
iii) मुख्य अभियंता (टी.ई.टी.डी.)

Annexure- 1

Additional operation norm for implementation of new environmental emission control measures 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 DeNOx system for control of NOx emission. The requirement of SOx and NOx to be complied is as below:

Sulphur Dioxide (SO_2)

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

Oxides of Nitrogen (NOx)

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

Presently, no relevant operational data is available on DeSOx and DeNOx systems in the country. The DeSOx systems are under implementation and 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.

A. DeSOx systems:

1. 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%.

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 =

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

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.

2. 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)
$Ca(OH)_2 + SO_2 + 1/2\ O_2 = CaSO_4 + H2_O$
(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. 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**, to be adjusted as per purity of actual limestone used.

3. **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%.

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**.

4. **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.

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

Specific consumption of limestone =

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

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.

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.

5. **Auxiliary energy consumption of FGD system:**

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. 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.

Sea water based FGD system:

Sea water based FGD is applicable for coastal locations. For power stations based on sea water once- through CW system, the auxiliary energy consumption of FGD system (without GGH) is proposed to be considered as 1% of gross output of the power plant.

Lime spray dryer/ semi dry FGD system:

Based on data furnished by OEM for typical lime spray dryer/ semi dry FGD system and information available on internet, 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.

Dry Sorbent Injection (DSI) System:

The auxiliary energy consumption in dry sorbent injection system involved in milling & pneumatic conveying of reagent is considered to be insignificant as compared to auxiliary energy consumption norm of power plant/ unit. As such, no norm is proposed for auxiliary energy consumption for dry sorbent injection (DSI) system.

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.

B. DeNOx systems:

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/Nm3 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:

$2\ NH_3 + 2\ NO + ½\ O_2 = 2\ N_2 + 3\ H_2O$
(2x17) (2x30)

$(NH_2)_2CO + 2\ NO + ½\ O_2 = 2\ N_2 + 2\ H_2O + CO_2$
(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.

1. 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.

For plants with permissible emission limit of 300 mg/Nm^3, take NOx reduction to be achieved = 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
(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 kg/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**.

2. Reagent consumption for plants using SCR to comply with NOx emission limit of 100 mg/Nm3

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 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%.
For estimating reagent consumption for 75- 85 % NOx reduction in SCR, take appropriate value of SR as 1.05.

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
(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 kg/kWh
Requirement of 100% ammonia = (17/46) x 1.05 x 1.469= 0.5702 g/kWh
Say 0.6 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 0.6 g/kWh**.

3. **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.

Recommendations:

The recommendations of CEA on admissibility of reagent consumption and auxiliary energy consumption on account of implementation of DeSOx system and DeNOx system towards compliance of new environmental emission norms are as below:

1. **Reagent consumption:**

i) *Limestone consumption of wet limestone based FGD system:*

Specific limestone consumption on gross generation basis =

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

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:*

Specific consumption 90% purity lime (CaO) on gross generation basis = **6 g/kWh**

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

Specific consumption of 100% sodium bicarbonate on gross generation basis = **12 g/kWh**

iv) *Limestone consumption of CFBC power plants (furnace injection):*

Specific limestone consumption on gross generation basis =

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

v) *Urea consumption of SNCR system:*

Specific consumption of 100% urea on gross generation basis = **1.2 g/kWh**

vi) *Ammonia consumption of SCR system:*

Specific consumption of 100% ammonia on gross generation basis = **0.6 g/kWh**

2. **Auxiliary energy consumption:**

i) *Wet limestone based FGD system:*

Normative auxiliary energy consumption for wet limestone FGD system= 1% of gross generation of the power plant.

ii) *Sea water based FGD system:*

Normative auxiliary energy consumption for sea water based FGD system= 1% of gross generation of the power plant.

iii) *Lime spray dryer/ semi dry FGD system:*

Normative auxiliary energy consumption for lime spray dryer/ semi dry FGD system= 1% of gross generation of the power plant.

iv) *Additional auxiliary energy consumption for provision of GGH:*

For FGD envisaged with GGH, additional auxiliary energy consumption= 0.3% of gross generation of the power plant/ unit.

v) *Additional auxiliary energy consumption for provision of SCR:*

Normative auxiliary energy consumption for installation of SCR system= 0.2% of gross generation of the power plant/ unit.

The above proposed norms for reagent consumption and auxiliary energy consumption in respect of DeSOx systems and DeNOx systems are suggested to be reviewed after sufficient operational data is available in due course of time.

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