Emission Control for Coal Fired Thermal Power Plants under the premise of Promulgated Indian Emission Standards

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Presentation Domain

- # Emissions from coal fired TPPs & control
- # Newly promulgated emission standards for Indian coal fired TPPs, revised timeline & challenges before the power industries
- # Current status on installation & commissioning of FGDs in Indian TPPs
- # Multi Pollutant Control Technology for coal fired TPPs – A critical review under Indian perspective
- # Research on CO_2 Capture in India: A brief assessment under the premise of new emission standards
- # Assessing the current Indian scenario
- # Concluding Recommendations

TPP: Thermal Power Plant
FGD: Flue Gas Desulfurization

Emissions from Coal Fired Thermal Power Plants & Control

Emissions from coal fired Thermal Power Plants

Sulfur Dioxide (SO_2)

Particulate Matter (PM)

Oxides of Nitrogen (NO_X)

$PM_{2.5}$ (aerodynamic diameter ≤ 2.5 µm)

PM_{10} (aerodynamic diameter ≤ 10 µm)

Mercury (Hg)

Elemental Mercury (Hg^0) (gaseous)

$Hg^0 + Hg^{2+} + Hg^P = Hg^T$

Particulate Mercury (Hg^P)

Oxidized Mercury (Hg^{2+}) (gaseous)

Carbon Dioxide (CO_2)

Volatile Organics

Carbon Monoxide (CO)

Composition of Flue Gas in Indian Coal fired Thermal Power Plants (TPPs)

Emission ranges of Air Pollutants

From plant (10 to 15) monitored data (Paliwal, CPCB)

- Particulate Matter (PM) = 30 – 350 g/Nm^3 [with ESP]
- Sulfur Dioxide (SO_2) = 800 – 1200 mg/Nm^3
- Oxides of Nitrogen (NO_x) = 200 – 700 mg/Nm^3
- Mercury (Hg) = 0.005 – 0.0185 mg/Nm^3

- Carbon Dioxide (CO_2) = 8 – 12 % [general range]

Ref.: S.K.Paliwal. Environmental Regulations for Coal based Thermal Power Plant. Central Pollution Control Board. Delhi , India. 17th WCAC & 9th BAQ Conference at Busan, South Korea Aug 29 – Sep 02, 2016

Control options to reduce PM Emission

Control of Emission of Particulate Matter (PM)

Electrostatic Precipitator (ESP)

Bag (Filter) House

Wet Scrubber

Device/s could be installed either alone or in combination depending upon the stringencies of emission regs & operating conditions

Control options to reduce SO_2 emission (Flue Gas Desulfurization: FGD)

Historic development of FGD

- **FGD studies began in 1850 (ca) in England**
- **1st Limestone based wet FGD commercialized in 1931 at Battersea Power Station under London Power Company**
- **Experiments on FGD in water commenced in 1960s**
- **Developed initially for catering Coal Fired TPPs**
- **Applied to TPPs using coal with S content ~ 3% (extended to low S coal also)**
- **Limestone based wet FGD reduces only SO_2 emission from the TPPs**

Ref.: A History of Flue Gas desulfurization Systems since 1850. JAPCA. 27, 10, 948–961, 1977
Kohl, A. & Nielsen, R. Gas Purification. Gulf Publishing. USA. 5th Ed. 1977

Summarized information on FGD for TPPs

Process	Alkaline Reagents	Inlet SO_2 (ppm_v)	By Products	Efficiency (%)
Lime Slurry	CaO	<100 - 6,500	Calcium based solids	90 - 95
Limestone Slurry	$CaCO_3$	1000 - 4,500		~95
Spray Drying – Lime	CaO, $Ca(OH)_2$	<100 - 3,000		90 - 95
Dual Alkali: Sodium + Lime stone or Lime	($NaOH/Na_2SO_3/Na_2CO_3$) & $CaCO_3$ or $Ca(OH)_2$	1,200 – 1,50,000		**99+**
Dual Alkali: Dowa	$CaCO_3$ & $Al_2(SO_4)_3$	1,000 - 25,000		85 - 98
Once Through Seawater	HCO_3^-	Up ~2,000		~98
Once Through Sodium	NaOH or Na_2CO_3	<100 - 10,000	Na_2SO_3; Na_2SO_4	**99+**

Ref. A.Bandyopadhyay & M.N.Biswas. Modeling of SO2 scrubbing in spray towers. Science of the Total Environment. 383, 25–40, 2007.

Some information about NO_x emission

Types of NO_x

THERMAL NO_x

- Generally the most significant.
- Formed by the simple heating of O_2 & N_2, either in a flame or by some other external heating, e.g., a lightning bolt.

PROMPT NO_x

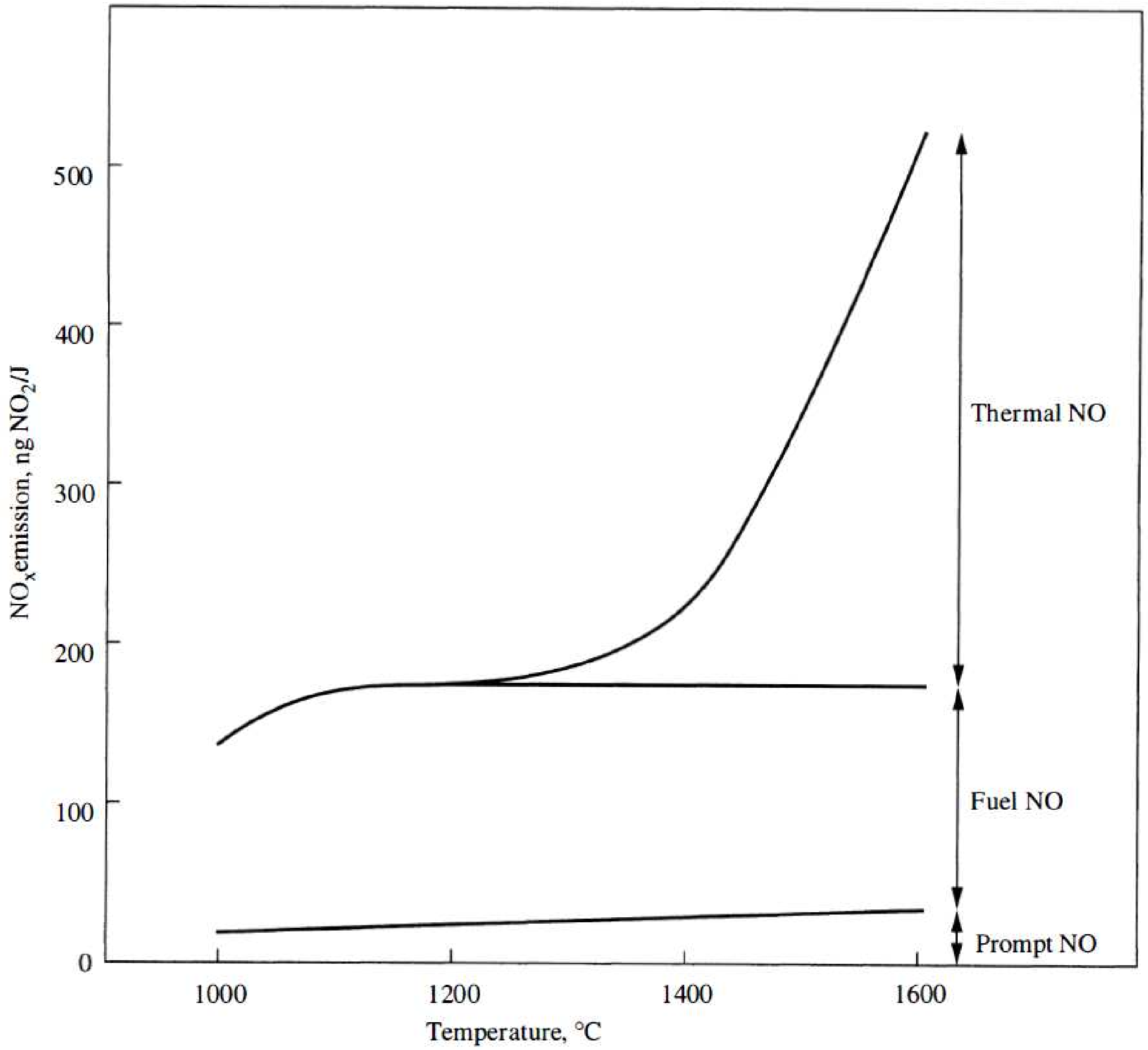
- Form very quickly as a result of the interaction of N_2 & O_2 with some of the active hydrocarbon species derived from the fuel in the fuel-rich parts of flames.
- They are not observed in flames of fuels with no carbon, e.g., H_2.
- They cannot be formed by simply heating O_2 & N_2.
- Participation of some active hydrocarbon species from the fuel is required.

FUEL NO_x

Formed by conversion of some of the N_2 originally present in the fuel to NO_x

Ref.: Noel de Nevers, Air Pollution Control Engineering. 2Ed, Waveland Press, Inc. 2000

Estimated contributions of 3 NO_x to total NO_x formation in coal combustion



Ref.: Noel de Nevers, Air Pollution Control Engineering. 2Ed, Waveland Press, Inc. 2000

Control options to reduce NO_x emission

- **COMBUSTION NO_x CONTROL PROCESSES**
- **POST-COMBUSTION NO_x CONTROL PROCESSES**
- **Combined NO_x/SO_2 processes**
- **Other NO_x- only processes**

COMBUSTION NO_x CONTROL PROCESSES

- **Low-Excess Air (LEA)** firings an efficient & practical operational control strategy since high excess air causes high NO_x emissions.
- **Over Fire Air (OFA)** allows fuel to burn initially with minimal air and sometimes at a deficiency of air (sub-stoichiometrically) with additional air introduced as over fire air. Over fire air ports are located above the highest elevation of burners.
- **Low-NO_x Burners (LNB)** reduce NO_x emissions by reducing the formation of thermal & fuel NO_x in the combustion area. This is accomplished by reducing flame temperatures by staging & controlling secondary air.

Ref.: Kohl, A. & Nielsen, R. Gas Purification. Gulf Publishing. USA. 5th Ed. 1997

Control options to reduce NO_x emission

POST-COMBUSTION NO_x CONTROL PROCESSES

Selective Non-Catalytic Reduction (SNCR) reduces NO_x via injection of ammonia or a urea-based reagent into the upper furnace &/or convection section (1500 -2200 ^{0}F) of the boiler.

Reaction with Urea: $CO(NH_2)_2 + 2NO + ½\ O_2 = 2N_2 + CO_2 + 2H_2O$

Possible byproducts due to poor process conditions (improper mixing, low residence time, lack of proper temperature etc.) are CO, high NH_3, and N_2O. There is no urea emission.

Reaction with Ammonia: $6NO + 4NH_3 = 5N_2 + 6H_2O$

For Temp >1750 ^{0}F: $4NH_3 + 5O_2 = 4NO + 6H_2O$

The reaction between NO_2 & NH_3 is not known for certain. However, field observations & calculations indicate that flue gas NO_2 concentrations are typically less than 5% of the total NO_x. Therefore, NO_2 is not a major concern based on NO_x reduction levels.

Ref.: Kohl, A. & Nielsen, R. Gas Purification. Gulf Publishing. USA. 5th Ed. 1997

Control options to reduce NO_x emission

POST-COMBUSTION NO_x CONTROL PROCESSES

Selective Catalytic Reduction (SCR) uses a catalyst to increase the rate of selective chemical reactions between NO_x & NH_3 to produce N_2 & H_2O. This process has the highest NO_x reduction capability (>90%) and is the most widely commercialized post-combustion control technology today.

Chemical Reactions are as following:

$$4NO + 4NH_3 + O_2 = 4N_2 + 6H_2O$$

$$2NO_2 + 4NH_3 + O_2 = 3N_2 + 6H_2O$$

$$6NO + 4NH_3 = 5N_2 + 6H_2O$$

$$6NO_2 + 8NH_3 = 7N_2 + 12H_2O$$

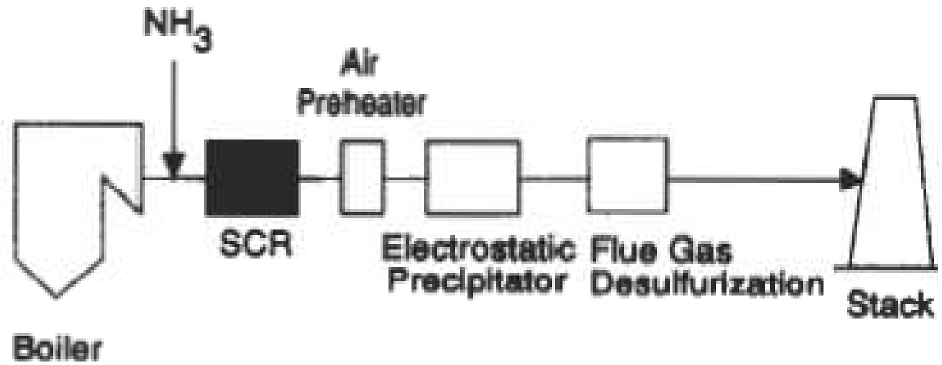
NH_3 concentration should be less than its LEL value

Reaction Temp: 500 – 750 ^{O}F

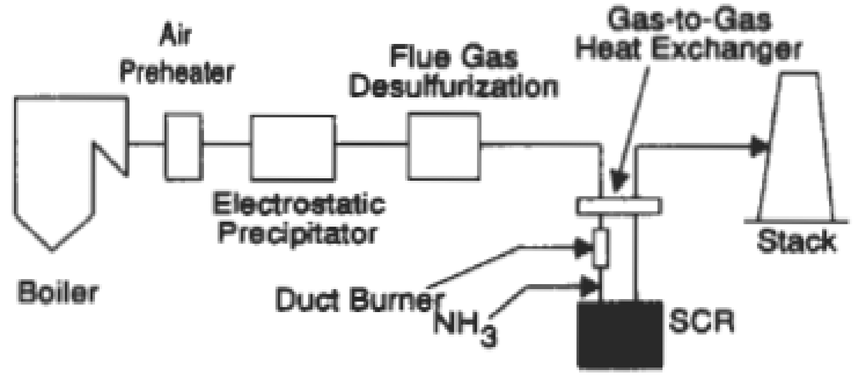
Ref.: Kohl, A. & Nielsen, R. Gas Purification. Gulf Publishing. USA. 5th Ed. 1997

Control options to reduce NO_x emission

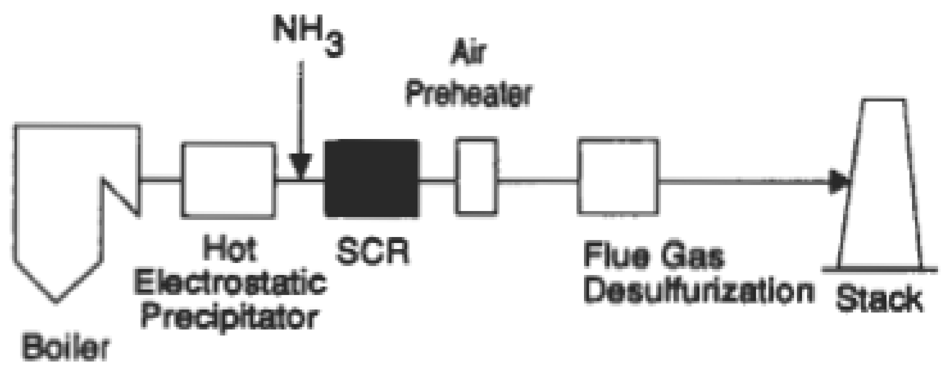
POST-COMBUSTION NO_x CONTROL PROCESSES



Hot-Side, High Dust SCR



Cold-Side, Low Dust SCR



Hot-Side, Low Dust SCR

Ref.: Kohl, A. & Nielsen, R. Gas Purification. Gulf Publishing. USA. 5th Ed. 1997

Various phases of Hg in flue gas & options of Hg emission control

Proportions of Hg in various phases depend on coal category, combustion condition, temperature, flue gas composition & other factors.

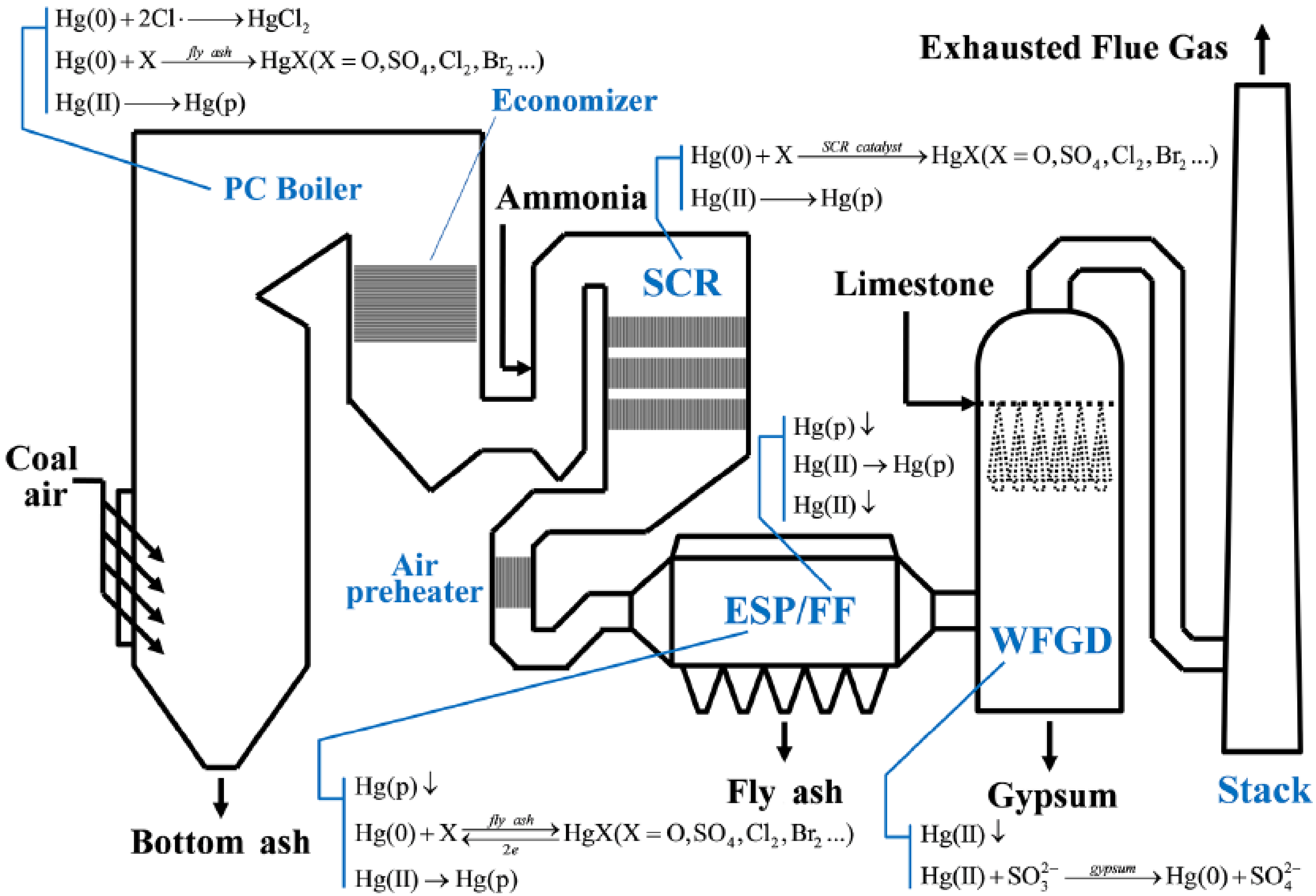
Speciation	Phase	Reduction Method
Hg^0	Gaseous	Mainly obtained from Sub-Bituminous & Lignite fired boilers; Hardly soluble in water as it is relatively stable & can be adsorbed under certain condition; Hard to be removed by conventional flue gas pollution control facilities in coal-fired power plants.
Hg^{2+}	Gaseous	Mainly obtained from Bituminous fired boilers; Soluble in water which can easily be captured in wet FGD and absorbed on the surface of solids.
Hg_P	Particulate	Removed in particulate collection devices (ESP/ Bag Filter/ Wet Scrubber)

Broad approaches for Hg emission control	(i) powdered activated carbon injection & (ii) enhancement of existing emission control devices

Total Mercury , $Hg^T = Hg^0 + Hg^{2+} + Hg^P$

Ref.: Li Bing, Wand Hongliang, Xu Yueyang, Xue Jianming. Effect of wet flue gas desulfurization facilities of coal-fired power plants on mercury emission. Energy Procedia 156 (2019) 128–132; USEPA.

Controlling air pollutants (including Hg) in TPPs



Ref.: Zhang et al. Mercury transformation and speciation in flue gases from anthropogenic emission sources: a critical review. Atmos. Chem. Phys., 16, 2417–2433, 2016

Newly Promulgated Emission Standards for Indian Coal Fired TPPs revised timeline & Challenges before the Power Industries

Promulgated Stack Emission Standards for TPPs Notified by MoEFCC, GoI on 07.12.2015

Parameters	All values are in mg/Nm^3		
	TPPs installed		TPPs to be installed
	Before 31.12.2003	01.01.2004 to 31.12.2016	After 01.01.2017
PM	100	50	30
SO_2	600 (< 500 MW) 200 (≥ 500 MW)	600 (< 500 MW) 200 (≥ 500 MW)	100
NO_x	600	300	100
Hg	0.03 (≥ 500 MW)	0.03	0.03

Ref.: **MoEFCC.** The New Emission Standards vide Notification No. S.O. 3305(E) dated 07.12.2015 in The Gazette of India: Extraordinary. Ministry of Environment, Forest and Climate Change. Government of India. New Delhi. 2015.
http://www.moef.gov.in/sites/default/files/Thermal%20plant%20gazette%20 scan.pdf

Revised action plan of Ministry of Power to meet new emission norms for TPPs (No. FU-1/2017-IPC dated 13.10.2017)

- 650 units (196667 MW): To meet new emission limits of SO_2, PM & NO_x.
- **SO_2 Emission**: 415 units (161522 MW): FGD to be installed by 2022
  [1 by 2018, 08 by 2019, 55 by 2020, 172 by 2021, 178 by 2022, 1 with 150 MW plan not received].
- **SO_2 Emission**: 235 units (35145 MW): either complying with limits or planned for phasing out, or have not submitted plan for FGD;
- **PM Emission**: 231 units (65925 MW): ESP upgradation for PM to be completed by 2022
  [1 by 2018, 2 by 2019, 28 by 2020, 97 by 2021, 94 by 2022, 9 with 1400 MW plan not received]
- Out of 414 units, 64 units FGD installation & upgradation of ESPs will be completed by 31.12.2020;
- **NO_x emission**: suggested to adopt pre combustion modification such as in situ modification in boiler, installation of Low NO_x burners & Over Fire Air besides installation of SCR/SNCR wherever needed by 2022;
- **Direction of MoEF&CC [F.No.Q-15017/40/2007-CPW dated 07.12.2017]**: CPCB to direct all TPPs to ensure compliance with notified norms of 07.12.2015 as per the above revised plan of MoP.

Ref.: Directions issued by CPCB under Section 5 of the Environment (Protection) Act, 1986 regarding compliance of emission limit notified vide notification No.S.0.3305 (E) dated 07.12.2015 to M/s The Tata Power Company Limited vide letter B-33014/07/2018/IPC-II/TPP/375 dated 06.04.2018; https://cpcb.nic.in/openpdffile.php?id=UHVibGljYXRpb25GaWxlLzE2MTNfMTUyMzg3MTM5OV9tZWRpYXBob3RvMzI1NzkucGRm

Current status on particulate-laden-gas cleaning to Indian TPPs

Particulate Matter (PM)	ESP with efficiency of 99.6% & Use of beneficiated coal
Sulfur Dioxide (SO_2)	Dispersion by Tall Stack
➢ Few TPPs operate with FGDs ➢ Initiatives have been taken to install FGDs to many TPPs (detailed later)	
Oxide of Nitrogen (NO_x)	Low NO_x burners
Mercury (Hg)	Existing APCD

Challenges before the Power Industry

- CPCB & CEA have recommended wet limestone based FGD technology
- Non availability of space/land in the plants installed prior to 31.12.2003 to retrofit:

  *FGD (to provide space for unit size ≥500 MW)

  *ESP (Possible to increase SCA/ conversion into hybrid ESP)
- Few years' time for implementation of new norms
- Non availability of proven technology for control of NO_x
- Availability of Limestone & Disposal of **Gypsum** (???)
- Substantial increase in tariff due to implementation of Norms

Trapped Hg?
Hazardous waste?

Ref.: S.K.Paliwal. Environmental Regulations for Coal based Thermal Power Plant. Central Pollution Control Board. Delhi , India. 17th WCAC & 9th BAQ Conference at Busan, South Korea Aug 29 – Sep 02, 2016; Record notes of discussions of the meeting on 8th Dec 2017 at NRPC, Katwaria Sarai New Delhi held under Chairmanship of Member (Thermal), CEA, New Delhi on 'Adherence to Environmental Norms as per Environment (Protection) Amendment Rules 2015 for Thermal Power Stations' with IPPs-installations of FGD. 2017a. Available at http://www.cea.nic.in/reports/others/ thermal/umpp/mom_ environmentalnorms.pdf accessed on February 16, 2018.

Current Status on Installation & Commissioning of FGDs in Indian TPPs

All India Installed Capacity of Coal Fired Thermal Power Stations (in MW)

Region	State	Private	Central	Total
Northern Region	16659	22425.83	14352.96	53437.79
Western Region	21740	32847.17	19147.95	73735.12
Southern Region	19782.5	12747	11835.02	44364.52
Eastern Region	7450	6153	13684.05	27287.05
North Easter Region	0	0	770.02	770.02
ALL INDIA (Total)	65631.5	74173	59790	199594.5
Data as on 30.11.2020 (Central Electricity Authority)				

Ref..: CEA, Govt of India. https://cea.nic.in/installed-capacity-report/?lang=en

FGD Progress Capacity (MW) for July 2020 [Central Electricity Authority]

Category	Central	Private	State	Total
FGD planned	55260	61237	53225	169722
Feasibility Study Started	55260	59327	51575	166162
Feasibility Study Completed	55260	53247	47515	156022
Tender Specifications Made	53370	45142	31865	130377
NIT Issued	53370	42742	26745	122857
Bids Awarded	34250	11160	2630	48040
FGD Commissioned	420	1320	0	1740
Total	307190	274175	213555	794920

Ref. https://cea.nic.in/dashboard/?lang=en accessed on December 23, 2020

FGD Progress Number of Units for July 2020 [Central Electricity Authority]

Category	Central	Private	State	Total
FGD planned	149	133	166	448
Feasibility Study Started	149	129	160	438
Feasibility Study Completed	149	111	152	412
Tender Specifications Made	140	90	97	327
NIT Issued	140	85	76	301
Bids Awarded	77	20	7	104
FGD Commissioned	2	2	0	4
Total	806	570	658	2034

Ref. https://cea.nic.in/dashboard/?lang=en accessed on December 23, 2020

Status of Indian FGDs

Company	Tata Power	Reliance	JSW	Adani	LANCO	NTPC	
Location	Trombay	Dahanu	Ratnagiri	Mundra	Udupi	Vindhyachal	Bongaigaon
State	Maharashtra			Gujarat	Karnataka	MP	Assam
Capacity, MW	500 & 250	500	4 x300	1980	2x600	Stg V: 500	750
Type of FGD	Seawater				Wet Limestone		
Area, m^2/Acres	7,200	-	-	1,500 (scrubber)	10,000	10,000–20,000	-
Water consmpn., 10^{-5} m^3/year	147.73	876–1051	-	1.25 –1.40	3.06–3.50	6.13–8.76	-
Auxiliary power consumption	1–1.5%	1.25%	0.5-1.5%	1.5%	0.5%	1.1%	-
Reagent, kg/ hr	–	–	–	–	–	6,250	-
Status	Operating	Operating	Under Construction	Planned	Operating	Planned	Under Construction
Manufacturer	ABB	Ducon	Alstom	-	Ducon	BHEL	BHEL

Ref.: M.L.Cropper, S.Guttikunda, P.Jawahar, K.Malik, I.Partridge. "Costs and Benefits of Installing Flue-Gas Desulfurization Units at Coal-Fired Power Plants in India" Ch # 13 in "Injury Prevention and Environmental Health". Disease Control Group: 3rd End. World Bank Group. 2017

Clearing the Air: Pollution-control technology for coal-based power plants. Research Directed by Priyavrat Bhati, Programme Director, Energy Group, Centre for Science & Environment (CSE), 2016.

Multi Pollutant Control Technology for Coal Fired Thermal Power Plants – A Critical Review under Indian perspective

Multi-Pollutant Control Technology (MPCT)

MPCTs developed for -

- Removing two or more pollutants in a single system
- To achieve new emissions standards
- Lower cost than series of single pollutant control systems

Assessing Four MPCTs for Indian case:

Sodium (NaOH or Na_2CO_3) based processes:

(i) Airborne™ Process

(ii) NeuStream® Technology

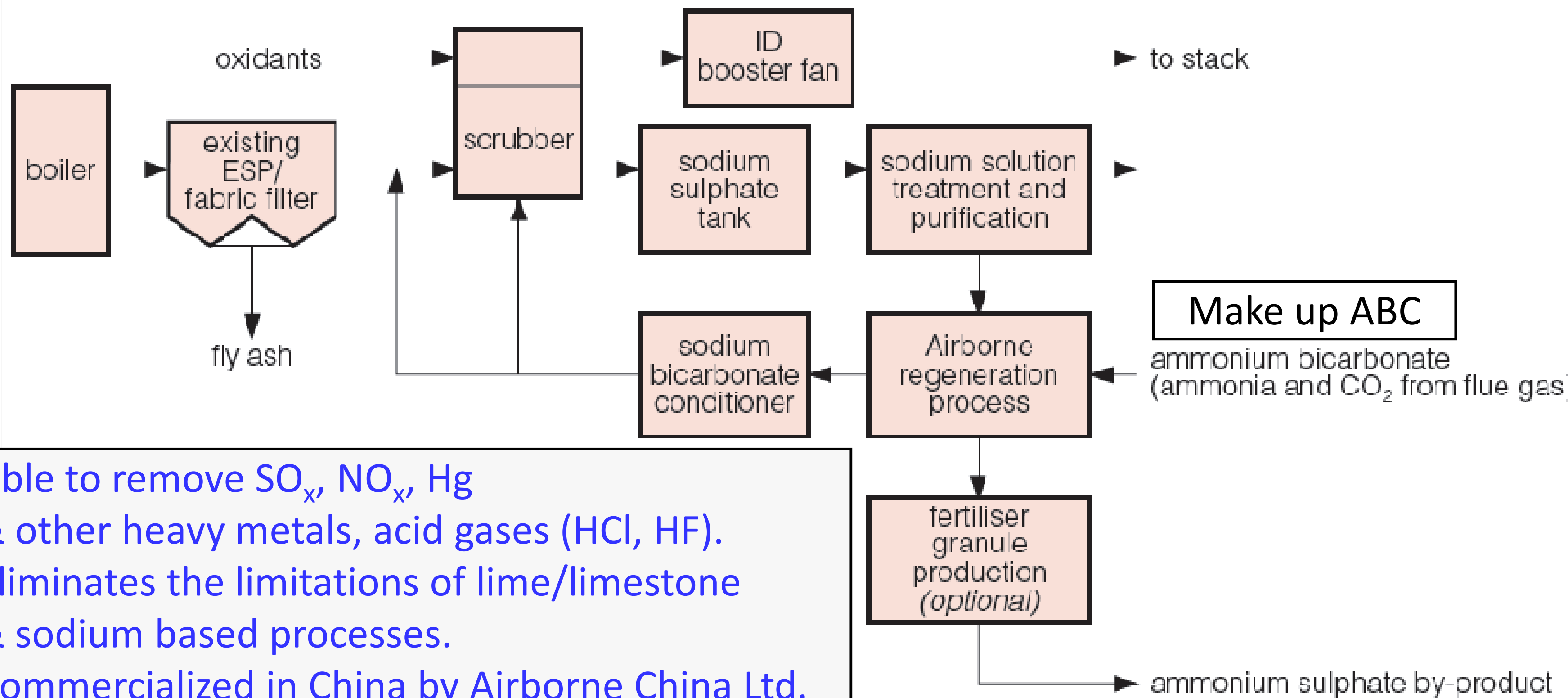
(iii) SkyMine®

Aqueous NH_3 based:

ECO®-ECO_2® Technology

Ref.: A.M. Carpenter. Advances in multi-pollutant control. IEA Clean Coal Centre. 2013

MPCT: Airborne™ Process



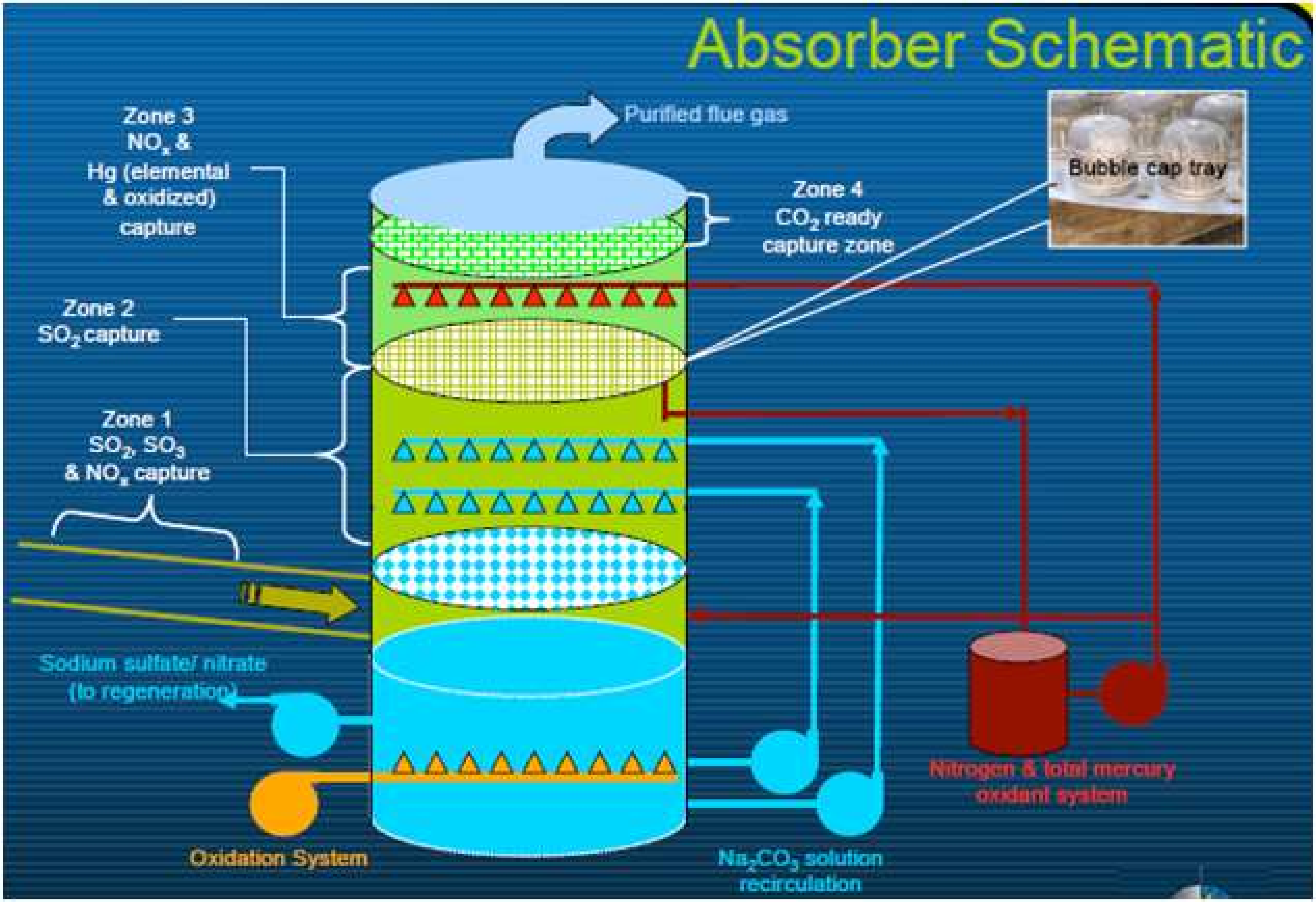
- Able to remove SO_x, NO_x, Hg & other heavy metals, acid gases (HCl, HF).
- Eliminates the limitations of lime/limestone & sodium based processes.
- Commercialized in China by Airborne China Ltd.

AB Catalyst is injected into the Boiler @ 200 g/t coal for enhancing combustion efficiency & reduced formation of SO_2, NO_x & heavy metals.
Saleable products: $(NH_4)_2SO_4$; NH_4NO_3
C-Neutral Approach: SO_x, NO_x & Hg stripped flue gas could be used as CO_2 source.
Removal: 99.9% (SO_2 + SO_3), 99% NO_x, 99% Hg.

Developer: Airborne Clean Energy Ltd, Calgary, Canada. www.airbornecleanenergy.com

Ref.: A.M.Carpenter. Advances in multi-pollutant control. IEA Clean Coal Centre. 2013
https://www.airbornecleanenergy.com/advanced-burning-catalyst accessed on December 23, 2020

MPCT: Airborne™ Process



Ref.: http://www.airbornecleanenergy.com/uploads/3/8/7/6/38765463/
cleancoalsummitconferenceacepresentationjune2006.pdf accessed on Oct 09/2016

MPCT: NeuStream® 3-Stage Process

Step # 1. NeuStream®-N (O_3 duct injection): Oxidizes NO_x & Hg after ESP

Step # 2. NeuStream®-S (dual-alkali FGD): removes SO_2, NO_x, HCl, HgO
Trona absorbs SO_2 & NO_X, lime regenerates solvent producing gypsum

Basis: 500 MW	Capex, US$ million	Opex, US$ million
NeuStream®-S	179.2	27.7
Conventional Wet FGD	394.4	54.3
Cost Savings for **NeuStream®-S**	~55%	50%

Step # 3. NeuStream®-C: Amine (Piperazine) absorption of CO_2

Removal: Up to 97% SO_2, 98% HCl, >90% oxidized Hg (~80% total Hg), >90% NOx & 70–90% CO_2

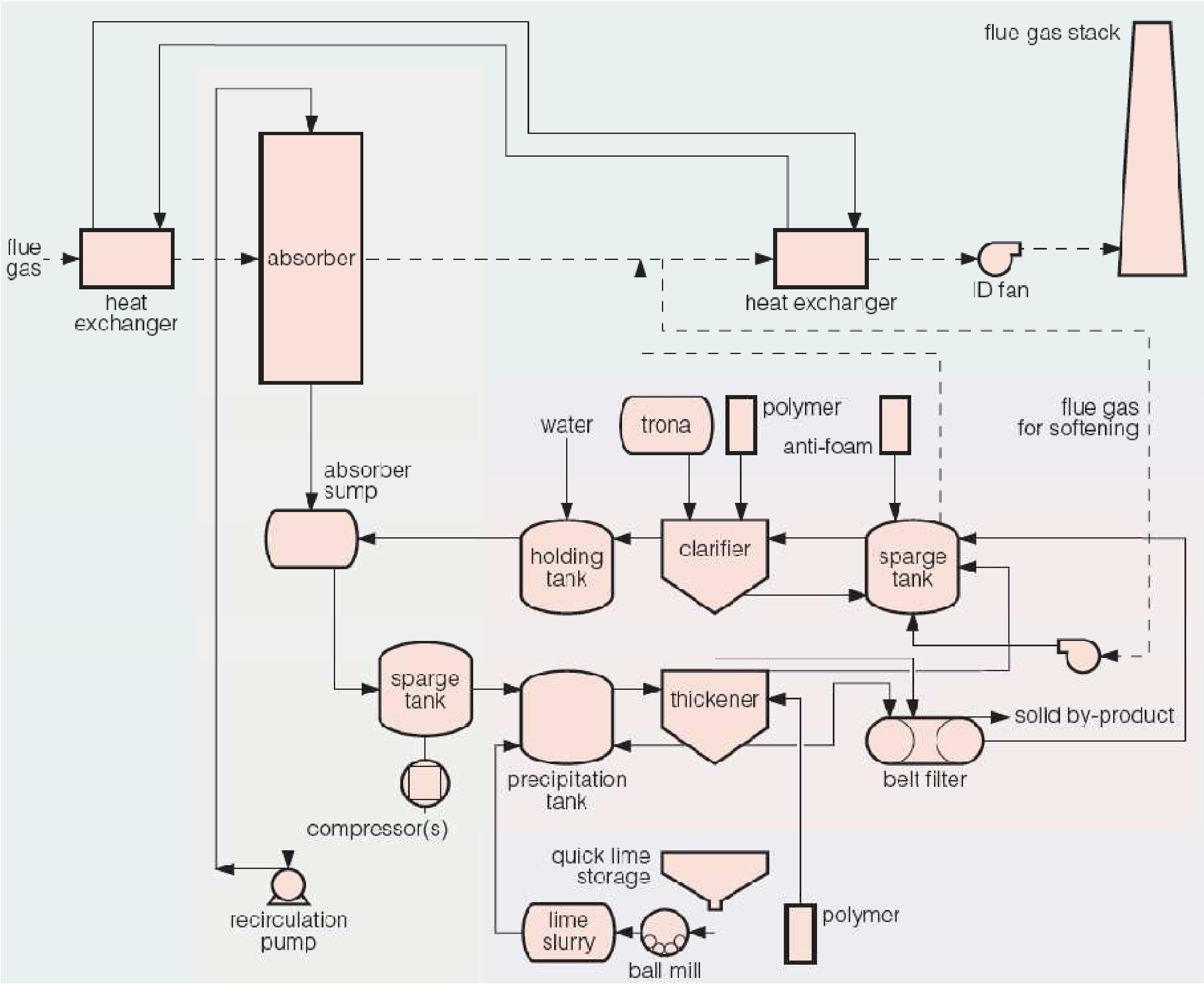
Environmental Problems of Amine: formation of carcinogenic nitramines & nitrosamines, formation of secondary aerosols, production of tropospheric ozone, risks from hazardous wastes (generated from the spent amine)

Commercial Status: Commercial demonstration

Developer: Neumann Systems Group. www.neumannsystemsgroup.com

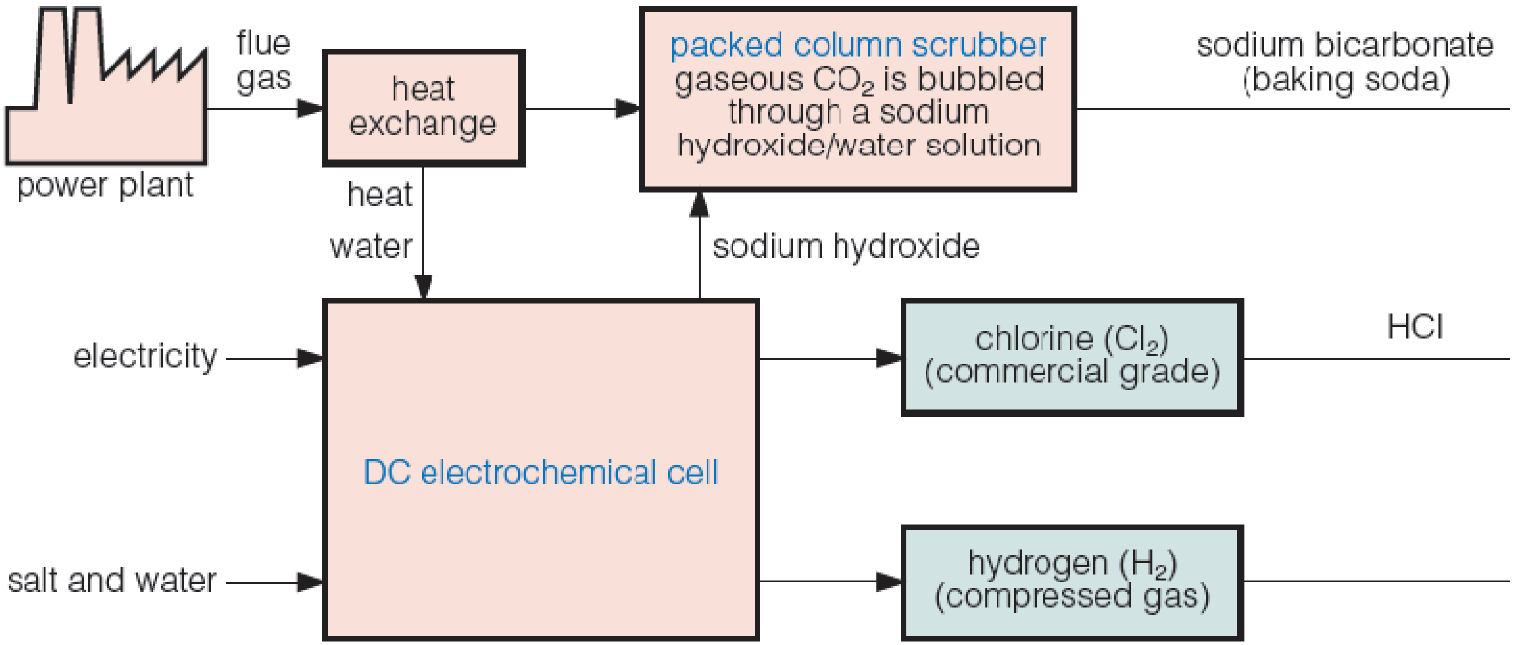
Ref.: A.M. Carpenter. Advances in multi-pollutant control. IEA Clean Coal Centre. 2013

MPCT: NeuStream®-S Process



Ref.: A.M. Carpenter. Advances in multi-pollutant control. IEA Clean Coal Centre. 2013

MPCT: SkyMine® Process



Reagent: NaOH from electrolysis of Brine. Saleable Products

SkyMine: Removes CO_2, SOx, NO_2, Hg & other heavy metals from flue gas

Cost: 600 billion USD for 1325 MW; 23 USD/t CO_2; Excluding revenue from products

Penalty: 20% as against 30 to 40% for CCS

Option (non-carbon mode) for removing SO_2, NO_2 & heavy metals (**SkyScrapper**)

Commercial Status: Commercial demonstration

Removal: >99% (SO_2 + NO_2), 90% Hg, 80–90% CO_2

Developer: Skyonic Corporation
http://skyonic.com.

Ref.: A.M. Carpenter. Advances in multi-pollutant control. IEA Clean Coal Centre. 2013

MPCT: ECO®-ECO_2® Technology

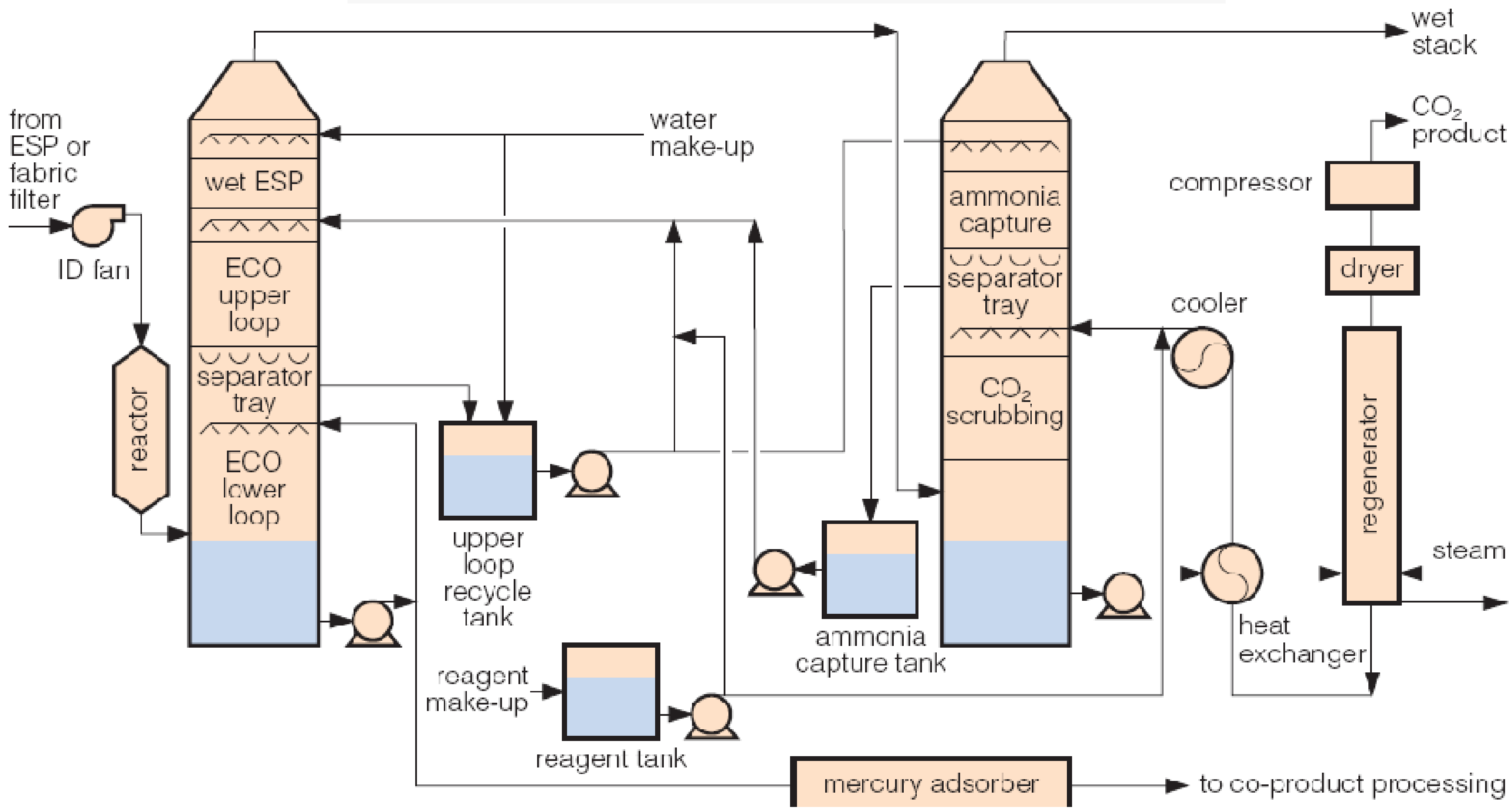
Step # 1. Dielectric Barrier Discharge (Plasma) Reactor: Oxidizes NO to NO_2; SO_2 to SO_3 & Hg to HgO
Step # 2. NO_2 & SO_2 reacts with water vapor in ECO® dual loop wet scrubber to form HNO_3 & H_2SO_4. Aq. NH_3 converts these acids here to NH_4NO_3 & $(NH_4)_2SO_4$ (Fertilizer products).
Step # 3. NO_2 & SO_2 scrubbed flue gas enters into ECO_2® scrubber to capture CO_2 followed by its thermal swing regeneration & compression for use while aq. NH_3 can be recycled.
Cost: Capital & operating costs are ~ 10–20% lower than conventional wet FGD + SCR
Removal: > 98% SO_2, >90% NOx, 98% HCl, >85% oxidized Hg, & 90% CO_2
Environmental Problems of Ammonia: Handling NH_3 attracts stringent safety measures & NH_3 slippage to atmosphere
Commercial Status: Yet to be demonstrated at full scale

Developer: Eco Power Technology Center in Louisville, KY, USA. http://powerspan.com

Ref.: A.M. Carpenter. Advances in multi-pollutant control. IEA Clean Coal Centre. 2013

MPCT: ECO®-ECO$_2$® Technology

Integrated ECO®-ECO$_2$® process



Ref.: A.M. Carpenter. Advances in multi-pollutant control. IEA Clean Coal Centre. 2013

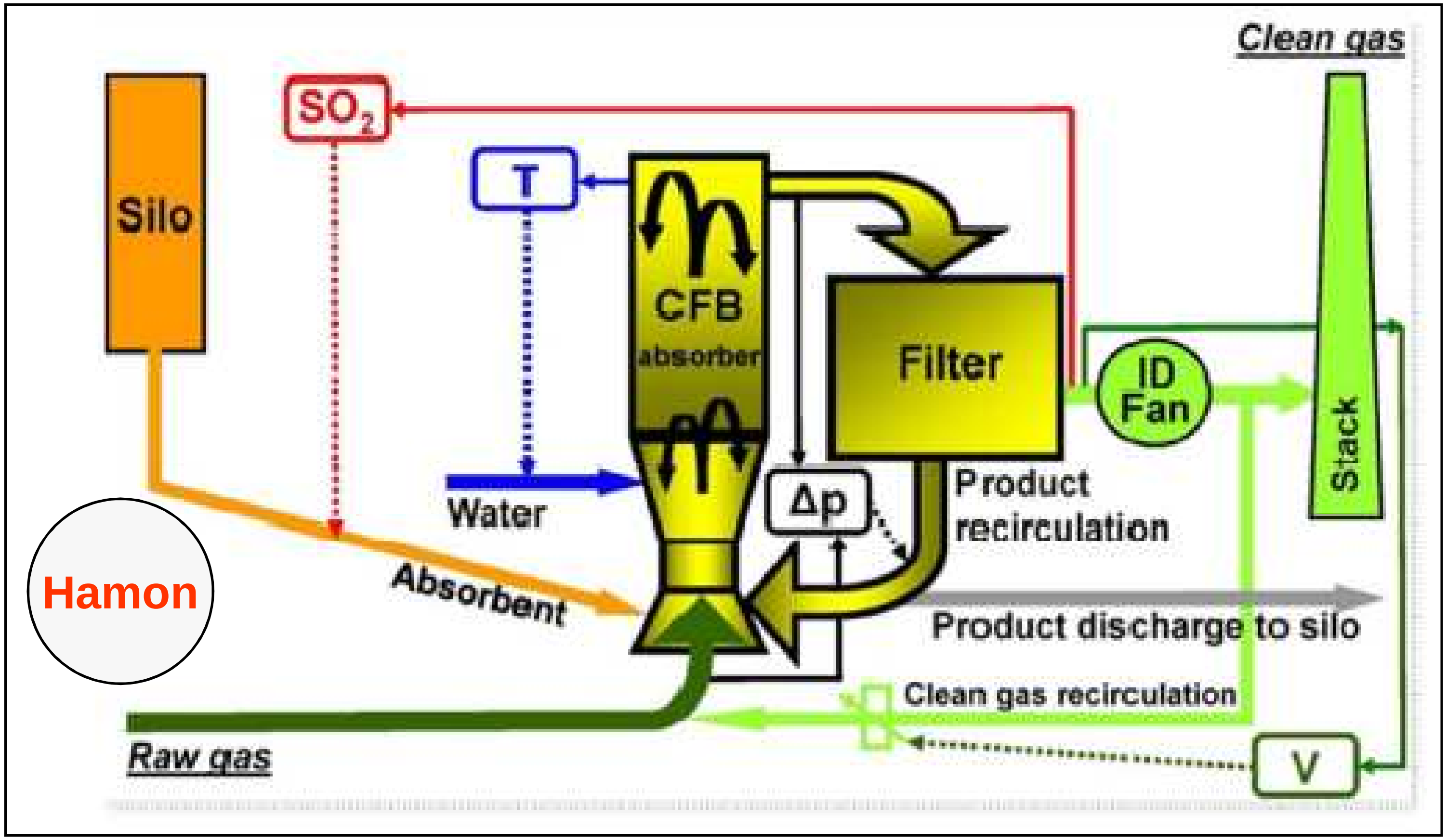
MPCTs vs Limestone Wet FGD for India

Process, Reagents & Products	Pollutants removed	Status
Limestone Wet Scrubbers (FGD) Limestone slurry as reagent. Gypsum (Hg trapped) is the by-product.	95–99% SO_2, <60% SO_3, >98% (HCl + HF), 75–99% oxidized Hg (>50% total Hg)	Commercial **No total emission control**
Airborne Process: Regenerable Na_2CO_3 injection with scrubbing & oxidant wash. Saleable fertilizers	99.9% (SO_2 + SO_3), 99.5% NOx, 99.5% Hg [C-neutral & CO_2 can be captured for use in the gas phase]	Commercial [$200-290/kW, 2005 estimate]
SkyMine: NaOH is reagent. Saleable carbonates &/or bicarbonates, H_2 & Cl_2	>99% (SO_2 + NO_2), 90% Hg, 80–90% CO_2	Commercial demonstration (cement plant)
NeuStream: O_3 injection for NO_x + dual-alkali scrubbing + CO_2 capture by Amines. Saleable by-products.	97% SO_2, >90% NOx, 98% HCl, >90% oxidized Hg, 70–90% CO_2 **Amine emission problem**	Commercial demonstration [$255-295/kW]
ECO®-ECO$_2$®: Plasma Oxidation Reactor, NH_3 scrubber for SO_2, NO_2 & CO_2	> 98% SO_2, >90% NOx, 98% HCl, >85% oxidized Hg, & 90% CO_2 **Ammonia leakage problem**	Commercial demonstration not yet done

MCPTs shown here are relatively less costly than wet FGD + SCR

Ref.: A.M. Carpenter. Advances in multi-pollutant control. IEA Clean Coal Centre. 2013; EPRI, 2011

Combined Removal of SO_x and PM
[Semi dry FGD technology on Circulating fluidized bed]



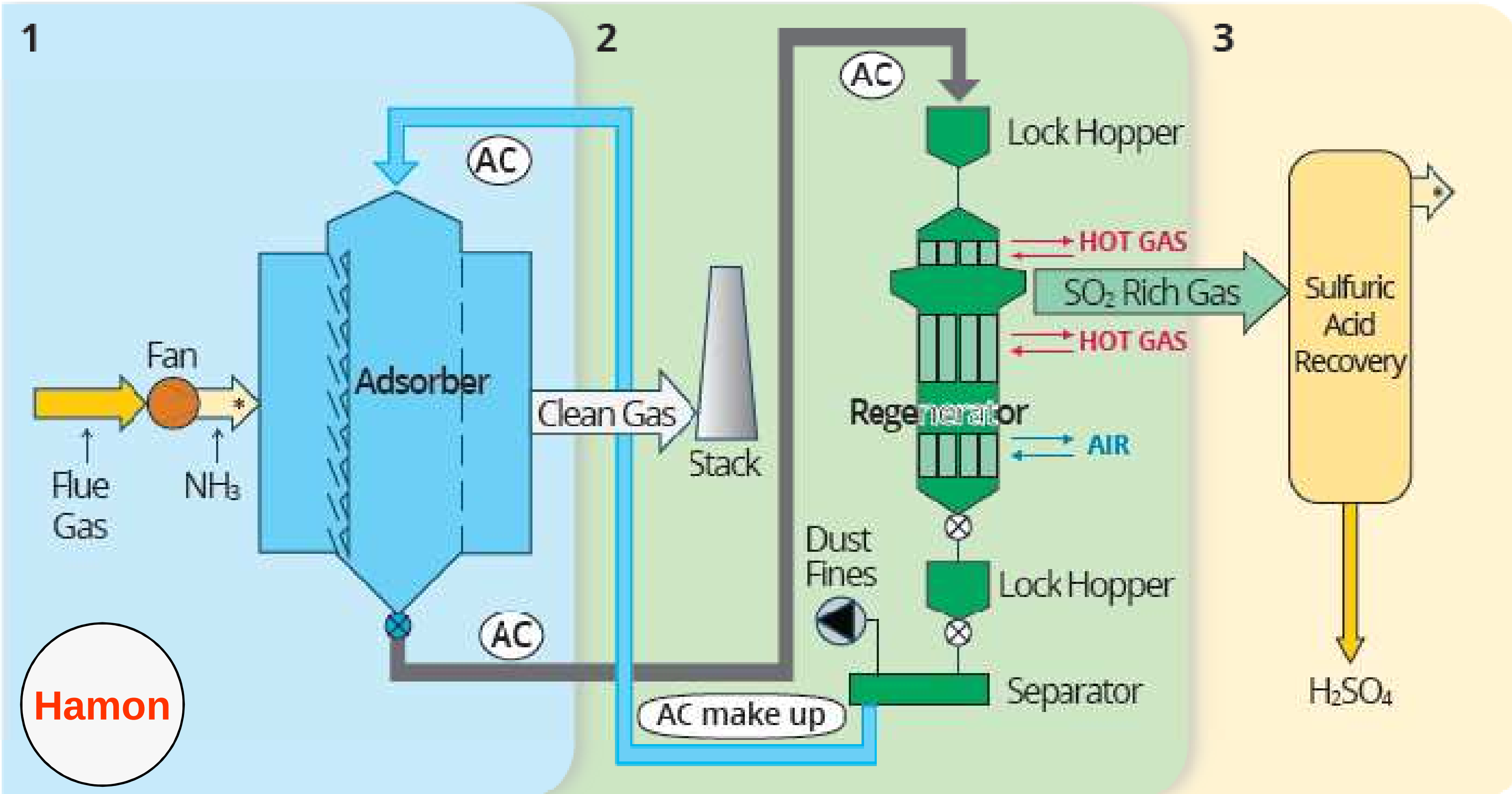
*** Desulphurization efficiency above 99 % can be achieved**

•No CO_2 Capture

•Dry Absorbent (Lime) & Product = Gypsum

Ref: http://soxnox.missionenergy.org/presentations/Hamon-R%20Singaravelu.pdf

Regenerative Activated Coke Technology: ReACT™



Ref.: http://scs.org/wp-content/uploads/2017/02/Session-7-ReACT-Brochure.pdf
Ref: http://soxnox.missionenergy.org/presentations/Hamon-R%20Singaravelu.pdf

Emission Reduction in ReACT™

- >95% to 99.9% SO_2(depending on equipment configuration)
- 25% to 80% NO_x (depending on equipment configuration)
- >95% mercury (including elemental species)
- Net reduction of PM
- Net reduction of Heavy Metals
- No CO_2 Removal/Capture
- Commercialized: Isogo Power Plant - 600 MW
- Product = Sulfuric Acid

Hamon

Hamon Research- Cottrell India Private limited: Office at Chennai

Ref: http://soxnox.missionenergy.org/presentations/Hamon-R%20Singaravelu.pdf

Critical Appraisal of MPCTs

Airborne Process™ & SkyMine® produce saleable by-products
Lower Carbon & water foot prints than limestone based wet FGD

Indian advantage is reported by **Dr. L.L.Sloss (Nov 2015)** -

*"**Pollution control technologies are expensive and take time to install. It would therefore make sense for India to coordinate pollution control systems and to focus as much as possible on multi-pollutant control systems which will reduce emissions of several pollutants simultaneously**."*

Poullikkas (2015) reported that the emerging technologies for combined control of SO_2 & NO_x emissions have the potential to curb these emissions for less than the combined cost of conventional wet FGD for SO_2 & SCR for NO_x controls. Some of these technologies are commercially used on low to medium sulfur coal fired TPPs.

Ref.: A.M. Carpenter. Advances in multi-pollutant control. IEA Clean Coal Centre. 2013
L.L.Sloss. *Coal in the Indian Energy future – emissions and policy considerations.* IEA Clean Coal Centre, Nov 2015.
Poullikkas, A. Review of Design, Operating, and Financial Considerations in Flue Gas Desulfurization Systems. Energy Technology & Policy. 2:1, 92-103, 2015.

Critical Appraisal of MPCTs: Cost Comparison

Pollution Control Technology	Capital Cost/MW (Rs)	O&M Cost/MW.annum
Case - I		
Wet FGD	Rs 50,00,000 (USD 72,175)	Rs 6,00,000 (USD 8,661)
Low-NO_x Burner + OFA	Rs 8,00,000 (USD 11,548)	0
Total	Rs 58,00,000	Rs 6,00,000
Hg trapped Gypsum disposal	?	?
Concerns: Revenue from Hg trapped Gypsum - ?. Hg emission from Gypsum disposal site.		
Case - II		
Wet FGD	Rs 50,00,000 (USD 72,175)	Rs 6,00,000 (USD 8,661)
SCR for NO_x control	Rs 30,00,000 (USD 43,305)	Rs 50,000 (USD 722)
Total	Rs 80,00,000	Rs 6,50,000
Hg trapped Gypsum disposal	?	?
Concerns: Revenue from Hg trapped Gypsum - ?. Hg emission from Gypsum disposal site.		

Pollution Control Technology	Cost Estimate/MW (vendor specified; 2005 estimate)
Air Borne MPCT	$ 200,000-290,000: Rs 14,000,000 – 20,300,000
System is ready for producing saleable fertilizer & no separate cost is involved. Revenue from saleable fertilizer is not known but it is favorable.	

Ref: The International Institute for Sustainable Development. 2019.
https://www.iisd.org/system/files/2020-08/india-energy-transition-air-pollution-standards.pdf
Accessed on 26th December, 2020 at 7.24 PM; & EPRI.

Research on CO_2 Capture in India: A brief assessment under the premise of newly promulgated Emission Standards for TPPs

Status of Indian Research on CO_2 Capture

Legion of R&D projects are funded by various Govt. agencies in India for CO_2 capture from simulated streams by various methods.

These researches ignore the estimated CO_2 generation from the processes developed to capture the CO_2.

Number of seminars etc. are being held in India for the past several years on CO_2 capture. In contrast, seminars or even funded R&D projects for SO_2 removal (or FGD) and MPCTs in India are few & far between before the promulgation of emission standards.

The major research areas towards CO_2 capture/removal include –
(i) developing membranes (inorganic/organic) for CO_2 capture,
(ii) absorption of CO_2 in amine based blended solvents,
(iii) removal of CO_2 on synthesized nano-materials as adsorbents.
(iv) biological methods for CO_2 capture.

Status of Indian Research on CO_2 Capture

Main thrust on R&D: Material development for CO_2 capture

Demonstration project commissioned on a slip-stream from the flue gas of an Indian TPP has not yet been reported.

Presence of other gases & traces of PM might not have yet been included in any of the Indian CO_2 capture projects.

These projects can not be directly put into practice in any Indian TPP without comprehensive studies taking into account of the plurality of pollutants present in the flue gas emitted from TPPs.

The life cycle analysis is mostly left out in the current Indian CO_2 capture projects which essentially constitutes an integral approach under the present circumstances.

Assessing the current Indian Scenario

Assessing the Indian Scenario

Newly promulgated Emission Standards for Indian cola fired TPPs are concentration based & not technology/equipment based.

Thus, Indian TPPs are free to choose any tech./equip. to meet the newly promulgated emission standards as per The Air (PCP) Act, 1981 & The Environment (Protection) Act, 1986.

Techno-enviro-economic solution is demanding to achieve the target.

Clarification of CEA (CEA, Dec 2017) *“…. presently CEA has come up with standard technical specifications for wet FGD, however, this is only advisory in nature and power producers have liberty to choose any suitable technology for reducing SO_x.”*

Thus there is a scope of selecting SO_2 removal technology other than wet limestone based FGD under Indian context.

Ref.: A.Bandyopadhyay. Cleaning, but with a better strategy. Write Back in Financial Express. P 9. March 16, 2017.
CEA: Record notes of discussions of the meeting on 8th Dec 2017 at NRPC, Katwaria Sarai New Delhi held under Chairmanship of Member (Thermal), CEA, New Delhi on ‘Adherence to Environmental Norms as per Environment (Protection) Amendment Rules 2015 for Thermal Power Stations’ with TPPs-installations of FGD. 2017a. Available at http://www.cea.nic.in/reports/others/ thermal/umpp/mom_environmentalnorms.pdf accessed on February 16, 2018.

A Paper on Plant Location Specific Emission Standards [Central Electricity Agency]

Background: Dispersion modelling study conducted by IIT Kanpur for the impact of Talwandi Sabo thermal power plant (District Mansa, Punjab) emissions to the ambient air quality.

Data used in the Modeling

- Exit Gas Velocity = 25 m/s (Full Load: 660 MW); 17 to 19 m/s (350 MW)
- Volumetric gas flow rate in the stack = 23,77,880 Nm^3/hr (dry basis)
- Stack gas Temp = 125 to 130 ^{O}C
- Stack Height = 275 m
- Stack diameter at top = 10.45m
- SO_2 emission rate = 2.77 kg/s for 1980 MW (0.975 kg/s for 660 MW)
- NO_x Emission rate = 0.55 kg/s (20% of SO_2 emission rate)

Findings of the Dispersion study: SO_2 levels of about 45.9$\mu g/m^3$ at the plant drop significantly to 1$\mu g/m^3$ at a distance of 40 km. Thus, beyond 40 km the impact of SO_2 becomes insignificant. Similar trend is seen for NO_x.

Ref.: https://cea.nic.in/?lang=en Uploaded on 21.12.2020; Accessed on 23.12.2020 at 10.00 PM.

National Ambient Air Quality Standards (NAAQS), 2009

Pollutants	Concentration in Ambient Air (values are in µg/m^3)			
	Industrial, Residential, Rural & other areas		Ecologically Sensitive areas (Notified by Central Govt.	
	Annual Average	24-hourly Average	Annual Average	24-hourly Average
SO_2	50	80	20	80
NO_2	40	80	30	80
PM_{10}	60	100	60	100
$PM_{2.5}$	40	60	40	60

Annual arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform intervals.

24 hourly or 08 hourly or 01 hourly monitored values, as applicable, shall be complied with 98% of the time in a year, 2% of the time, they may exceed the limits but not on two consecutive days of monitoring.

Note: Whenever and wherever monitoring results on two consecutive days of monitoring exceed the limits specified above for the respective category, it shall be considered adequate reasons to institute regular or continuous monitoring and further investigation

AQI categories & health breakpoints for air pollutants

AQI Category	AQI	Concentration ($\mu g/m^3$) range 24-hourly average values			
		PM_{10}	$PM_{2.5}$	NO_2	SO_2
Good	0 - 50	0 - 50	0 - 30	0 - 40	0 - 40
Satisfactory	51 - 100	51 - 100	31 - 60	41 - 80	41 - 80
Moderately polluted	101 - 200	101 -250	61 - 90	81 -180	81 - 380
Poor	201 - 300	251 -350	91 -120	181 -280	381 -800
Very poor	301 – 400	351 -430	121 -250	281 -400	801 -1600
Severe	401 - 500	430 +	250+	400+	1600+

Used in the study reported by CEA

Out of 8, 4 air pollutants are mentioned here for the purpose of current analysis

Ref.: About National Air Quality Index.
https://cpcb.nic.in/displaypdf.php?id=bmF0aW9uYWwtYWlyLXF1YWxpdHktaW5kZXgvQWJvdXRfQVFJLnBkZg==

A Paper on Plant Location Specific Emission Standards [Central Electricity Agency]

Capacity wise Classification of TPPs followed by Phasing of FGD Installation based on levels of 24-hrly avg (max) SO_2 Concentration in the vicinity of TPPs

Region	Levels SO_2 Concentration in the Ambient Air (values are in μg/m^3)		Total Capacity (MW)	Remarks
1	Level-I	>40	1,460	FGD shall be installed immediately
2	Level-II	>30 & ≤40	5,048	FGD shall be installed in 2nd phase, may be after 1 year of commissioning of 1st phase units & observing the effectiveness of installed equipment.
3	Level-III	>20 & ≤30	290	FGD is not required at present
4	Level-IV	>10 & ≤20	17,890	FGD is not required at present
5	Level-V	>0 & ≤10	11,020	FGD is not required at present

AAQ data of many Indian places (CPCB) and SO_2 monitored data reported by TPPs along with the findings of the dispersion study have been used to make the classification.

Ref.: https://cea.nic.in/?lang=en Uploaded on 21.12.2020; Accessed on 23.12.2020 at 10.00 PM.

A Paper on Plant Location Specific Emission Standards [Central Electricity Agency]

Reported Concerns:

- There should be graded action plan for adopting new emission norms for TPPs as proposed rather than adopting a single deadline for large base of power plants across the country.
- An unworkable time schedule will create market scarcity leading to import, jacked up prices unnecessary burden on power utilities.
- Graded action plan will help in utilizing the resources in effective manner and it will help in fine tuning the technology for local conditions.
- If the process of emission control is completed in 10-15 years' time frame for TPPs located in critically polluted areas in first phase, it will help in developing indigenous manufacturing base, skilled manpower in the country which shall take care of the local operating conditions.

Ref.: https://cea.nic.in/?lang=en Uploaded on 21.12.2020; Accessed on 23.12.2020 at 10.00 PM.

Concluding Recommendations

Concluding Recommendations

1. **A Task Force at national level under the aegis of MoEFCC/ CPCB & CEA may be constituted to monitor the compliance status of the newly promulgated emission standards**

   Proposed composition of the Task Force -

   i) Experts from MoP, MoC, MoEFCC, CPCB, CEA, CERA, POSOCO

   (ii) Experts from TPPs like NTPC/DVC/SEBs

   iii) Experts from Inorganic Chemical & Fertilizer Industries

   iv) Technology Field Experts -

   (a) Emission Control/ Gas Cleaning Technology

   (b) CO_2 Capture & Sequestration (Geologic/CO_2 Reuse)

   v) Policy Experts

CEA: Central Electricity Authority;
CERC: Central Electricity Regulatory Commission
POSOCO: Power System Operation Corporation Limited

Ref.: A.Bandyopadhyay. Assessing the Current Practice and Policy with Recommendations for Emission Control Strategy for Coal Fired Thermal Power Plants under Indian Regulatory Framework emphasizing the Roles of R&D. Environmental Quality Management for publication, 27, 49–55, 2017b"; https://doi.org/10.1002/tqem.21511

Concluding Recommendations

2. To consider revamping ESP for controlling emission of fly ash.
3. To consider a single technology for cleaning multiple pollutants than installing a standalone FGD system, without ignoring CO_2 capture though it is not a listed parameter in the promulgated emission standards.
4. To consider market potential of the by-products of gas cleaning so that the same may not create disposal problems like gypsum.
5. For CCS, to consider Zoning– typical examples are

TPPs located at Durgapur, WB may have CCS for ECBMR

TPPs located elsewhere, e.g., at Mejia, WB may have MCPT with saleable by products (avoiding CCS project here).

Ref.: A.Bandyopadhyay. Assessing the Current Practice and Policy with Recommendations for Emission Control Strategy for Coal Fired Thermal Power Plants under Indian Regulatory Framework emphasizing the Roles of R&D. Environmental Quality Management for publication, 27, 49–55, 2017b"; https://doi.org/10.1002/tqem.21511

Concluding Recommendations

6. To consider utilization of captured CO_2 as
   (i) saleable products &
   (ii) sequestration as in CCS projects e.g. in ECBMR.
7. Indian Power Sector may like to establish collectively National Emission Control Technology Research Centre (including Research on CO_2 Capture) indicating the role of Indian R&D towards industrial gas cleaning (business to business or multi-sectoral approach) targeting lower water- & carbon- footprints.
8. To consider support for other logistics, if any.
9. To follow the principle of Charter on Corporate Responsibility of Environmental Protection (CREP) for developing “Technology Guidelines”.

Ref.: A.Bandyopadhyay. Assessing the Current Practice and Policy with Recommendations for Emission Control Strategy for Coal Fired Thermal Power Plants under Indian Regulatory Framework emphasizing the Roles of R&D. Environmental Quality Management for publication, 27, 49–55, 2017b”; https://doi.org/10.1002/tqem.21511

Concluding Recommendations

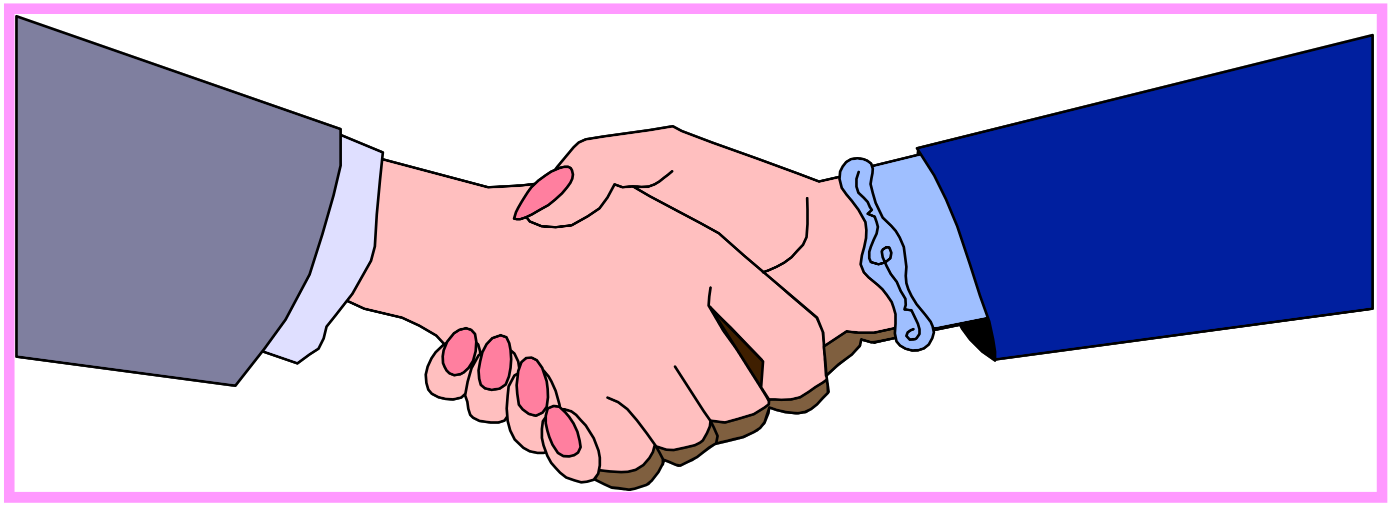
10. To propose Capacity Building Programme on Advanced Emission Control Technology for TPPs, SPCBs/ PCCs/ CPCB for framing post-implementation strategies.
11. To plan for (i) regular Stack Emission monitoring for air pollutants & (ii) AAQ Monitoring for relevant parameters in the vicinity of the TPPs coupled with dispersion modeling that will help future planning & decision making.
12. "Gas Cleaning Plants" require the knowledge of thermodynamics, chemical kinetics & mass transfer. "*Chemical Engineers*" are appropriately equipped with such knowledge.
13. Indian TPPs will require "*Chemical Engineers*" for meeting the challenges of the new emission standards. Outsourcing of experts may not be conducive in the long run.
14. Submission of recommendations by the *Task Force* to the Government of India for consideration.

Ref.: A.Bandyopadhyay. Assessing the Current Practice and Policy with Recommendations for Emission Control Strategy for Coal Fired Thermal Power Plants under Indian Regulatory Framework emphasizing the Roles of R&D. Environmental Quality Management for publication, 27, 49–55, 2017b"; https://doi.org/10.1002/tqem.21511

Experience in Inspecting Coal Fired Thermal Power Plants for Compliance of Parameters listed in EC/CoO

Number of inspections made to coal fired Thermal Power Plants while associated with WBPCB

Sl #	Name of the Thermal Power Station	Capacity	Number of visits
1	Durgapur Projects Limited	2x30 MW 3x77 MW 110 MW	10 (27.04.1998 to 05.12.2001)
2	Durgapur Thermal Power Plant, DVC	140 MW 210 MW	07 (29.04.1998 to 19.09.2001)
3	Santaldih Thermal Power Plant	4x120 MW	03 (09.10.1998 to 01.03.2001)
4	Dishergarh Power Supply Corporation Ltd. Dishergarh Unit	3x10 MW	04 (29.08.1999 to 26.12.2001)
5	Dishergarh Power Supply Corporation Ltd. Chinakuri Unit	3x5 MW 3 MW	03 (29.08.1999 to 01.11.2000)
6	Mejia Thermal Power Plant, DVC	3x210 MW	03 (24.12.1999 to 21.11.2001)
7	Bakreshwar Thermal Power Plant	3x210 MW	03 (06.01.2001 to 08.11.2001)
8	Durgapur Steel Plant: Captive Power Plant	2x60 MW	09 (28.07.1998 to 06.12.2001)
9	Kolaghat Thermal Power Plant	6x210 MW	15 (21.01.2002 to 15.03.2004)
10	CESC, Budge Budge Thermal Power Plant	3x250 MW	18 (25.05.2004 to 29.05.2007)
	TOTAL		**75 (27.04.1998 to 29.05.2007)**



Thank You