



Electrostatic Precipitation: Present and Future

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Prof. dr. Keping Yan received the B.S. and M.S. degrees in applied physics from Beijing Institute of Technology (BIT), and Ph.D. degree in Electrical Engineering from Eindhoven University of Technology (TU/e), The Netherlands, respectively. From 1986 to 2006, he was with BIT, Padova University, Oita University, ENEL, and TU/e. In 2006, he joined the Zhejiang University, China, as a Full Professor.



Since 1986, his education and R&D activities have been in environmental engineering and science, the applied plasma and electrostatic precipitation. As a coauthor, he published more than 140 papers in journals or chapters.

He received several national and international awards including the blue sky award from Chinese ESP committee, the marine technique achievement award from Chinese marine committee, the Frederick G. Cottrell Award from the ISESP, and the 2019 ISEHD J.S. Chang lecture award.

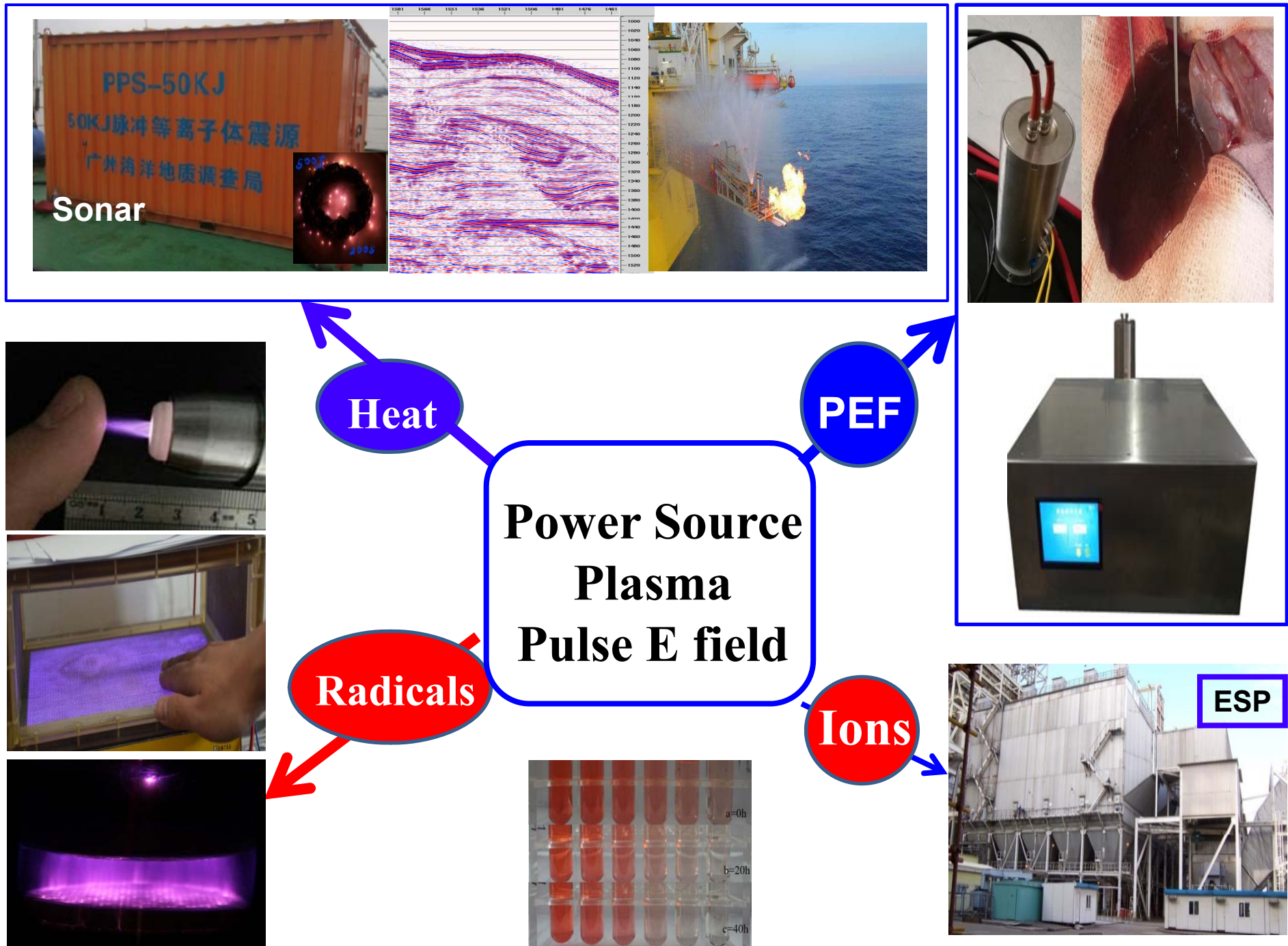
Since 2004, he has been a board member and the president (2008-2011) of the International Society of Electrostatic Precipitation (ISESP).

Personal page: <http://mypage.zju.edu.cn/isesp/>

Outline

- 1. Overview of Our R&D**
- 2. How to size and operate ESP**
- 3. ESP to NTP Fundamentals**
- 4. Industrial Demonstrations**
- 5. Future Prospects**

Energy + Environments + Health



Overview of Chinese National Standards

**Coal-fired boilers:
Ultra-Low Emission**

2003

PM: 50mg/m³
NOx: 450-1000mg/m³
SO₂: 400-1200mg/m³

2011

PM: 30mg/m³
NOx: 100-200mg/m³
SO₂: 200mg/m³

2014

PM: 20mg/m³
NOx: 100mg/m³
SO₂: 50mg/m³

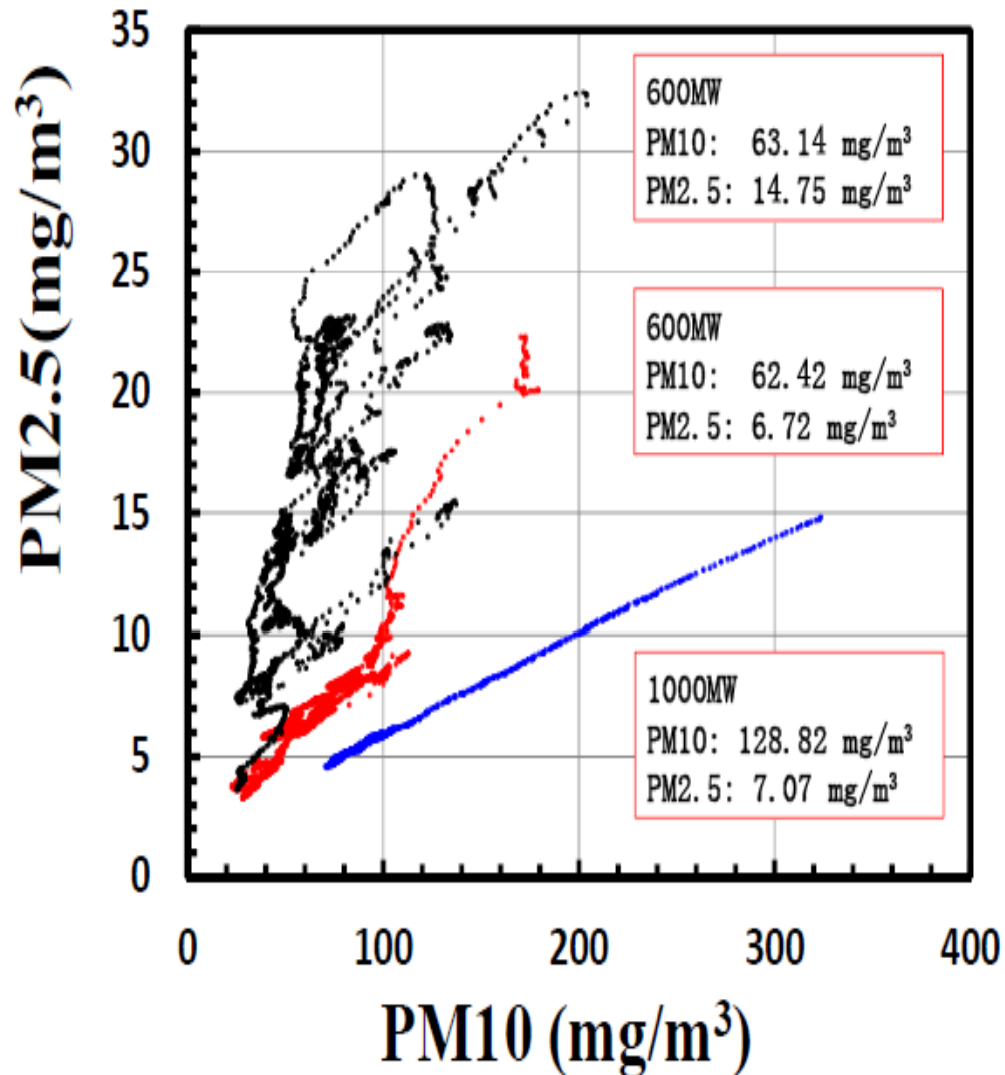
2015

PM: 10mg/m³
NOx: 50mg/m³
SO₂: 35mg/m³

Today Region or Utility

PM: 1-5mg/m³ NOx: 10-30mg/m³ SO₂: 17mg/m³

How to Size and Operate ESP?



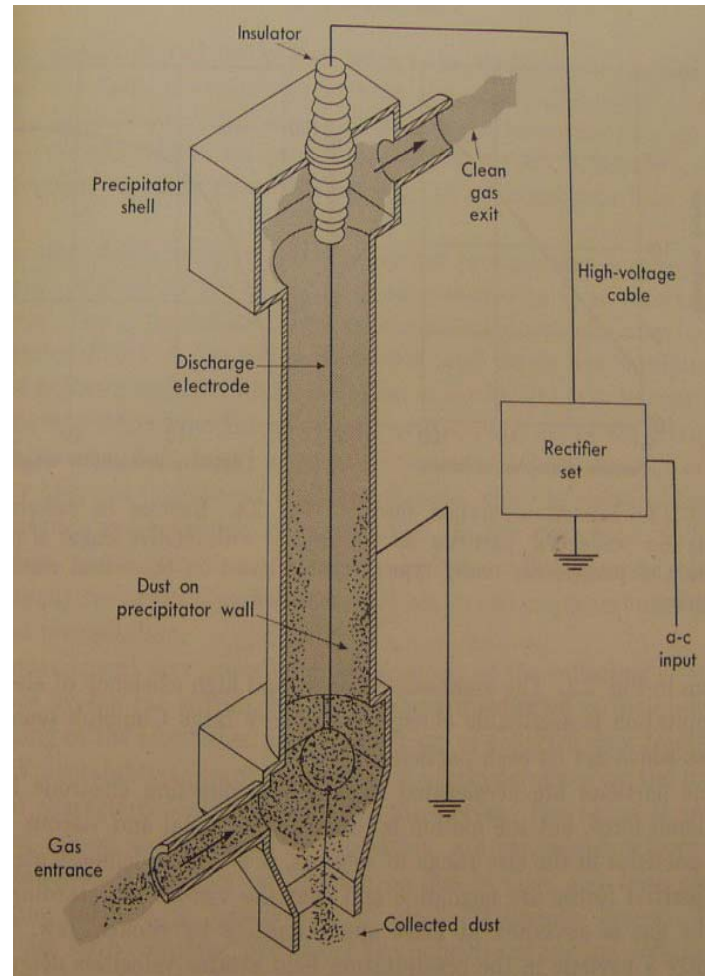
ESP outlet PM:
50-100 mg/Nm³

How to control PM
below 5 mg/Nm³ ?

How to control PM2.5 to
below 2.5 mg/Nm³ ?

How to size and/or
upgrade ESP ?

Principle of Electrostatic Precipitation



ESP & Gas Temp

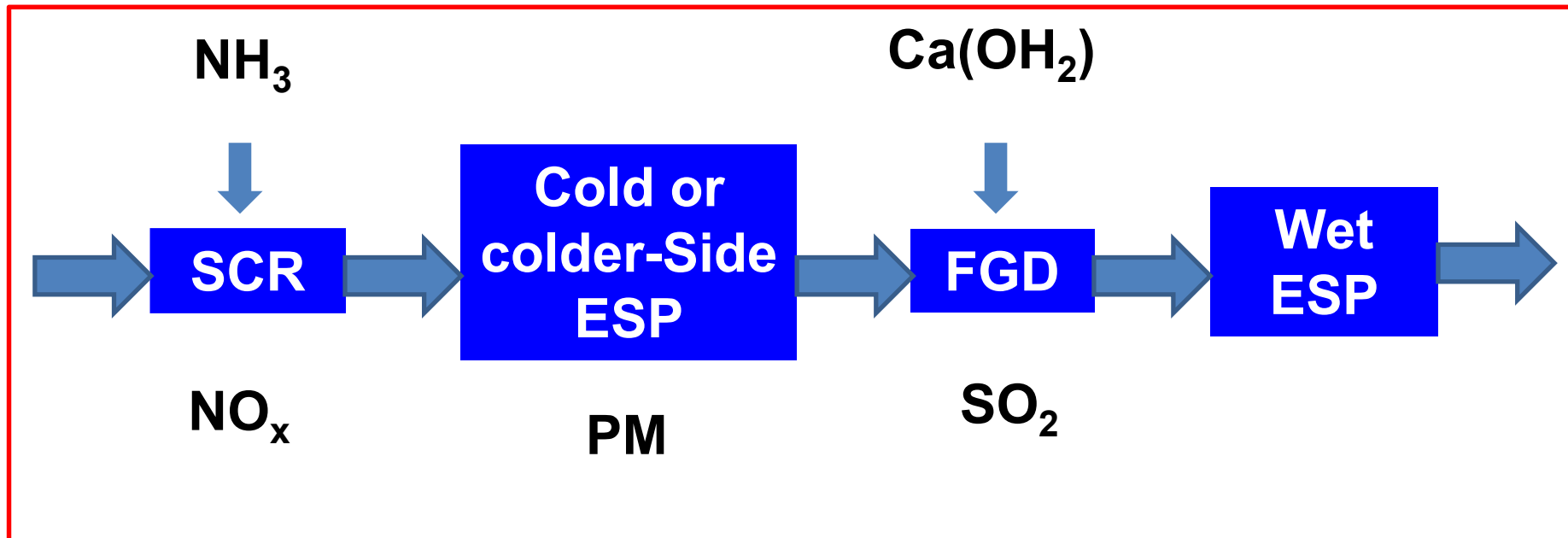
1. $T > 300^{\circ}\text{C}$, hot-side ESP;
2. $T > T(\text{SO}_3 \text{ dew point})$, cold-side ESP;
3. $T < T(\text{SO}_3 \text{ dew point})$, colder-side ESP;
4. $T < T(\text{H}_2\text{O dew point})$, wet ESP

H.J. White, Industrial
Electrostatic Precipitation, 1963

Gas Cleaning System

Coal-fired Power Plant

PM $\leq 10\text{mg/m}^3$
NO_x $\leq 50\text{mg/m}^3$
SO₂ $\leq 35\text{mg/m}^3$
Hg $\leq 3\mu\text{g/m}^3$



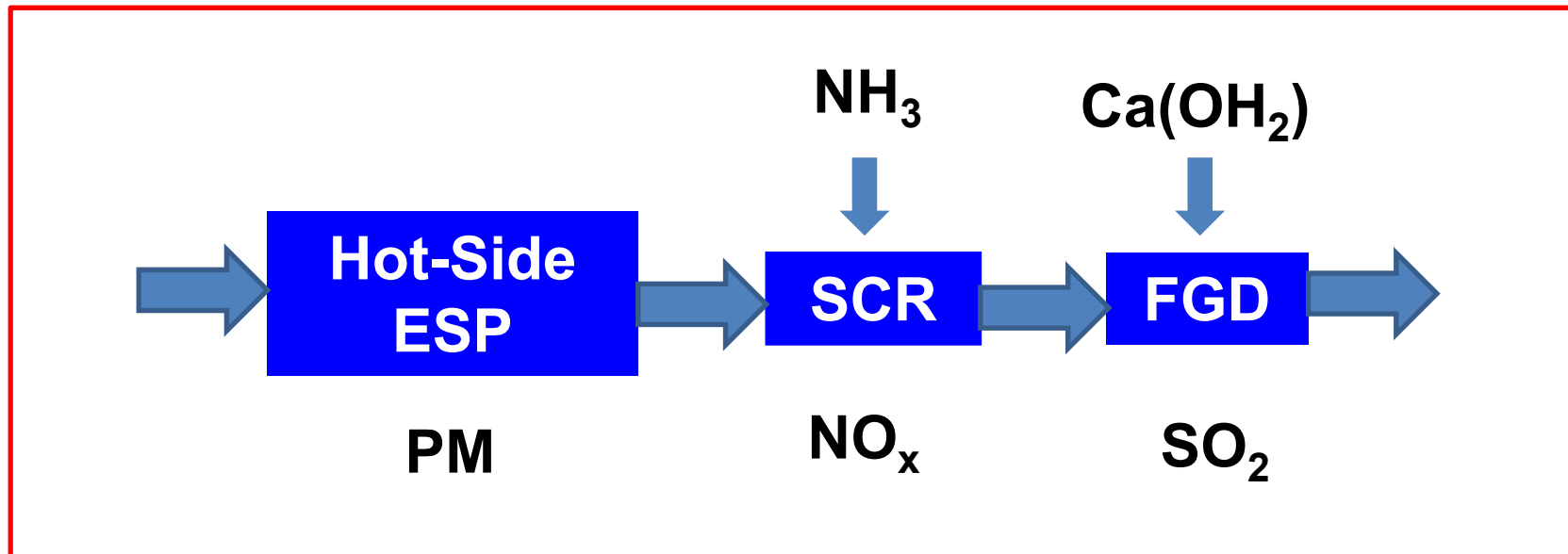
Gas Cleaning System

PM $\leq 10\text{mg/m}^3$

NO_x $\leq 50\text{mg/m}^3$

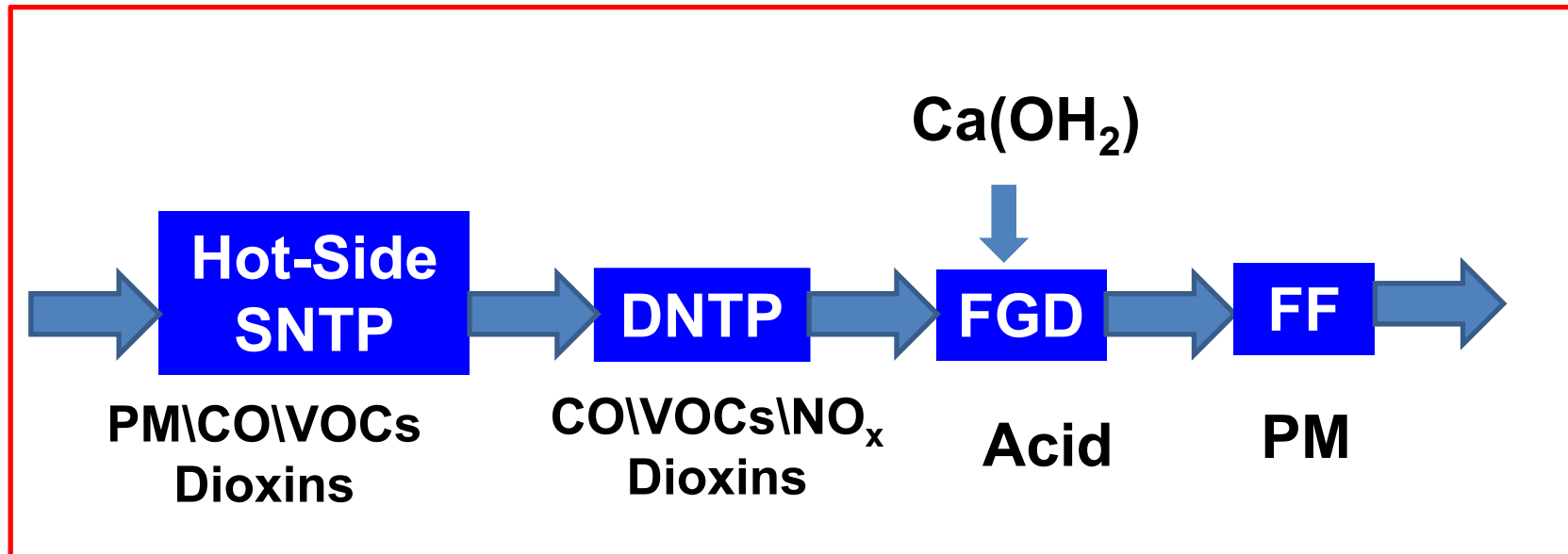
SO₂ $\leq 35\text{mg/m}^3$

Glass、coking and Cement Industries

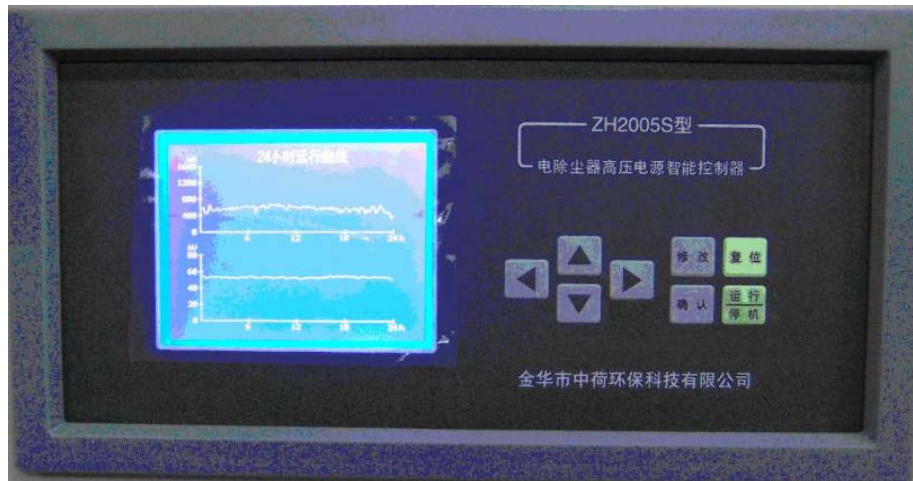


Gas Cleaning System

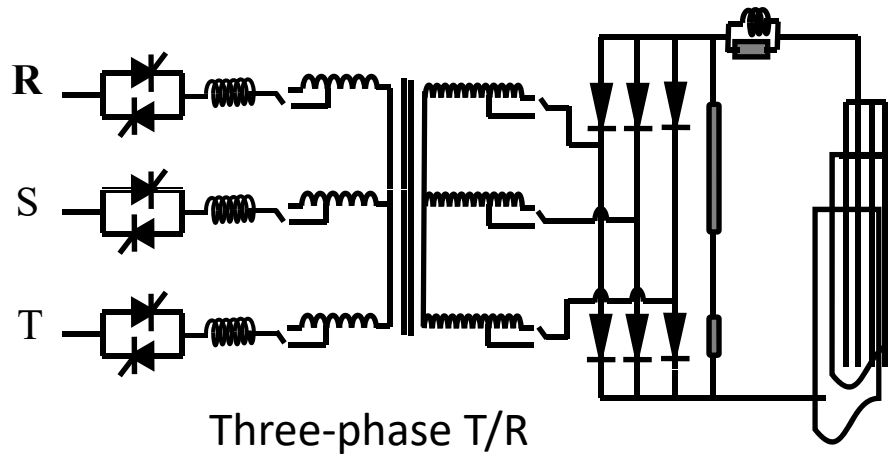
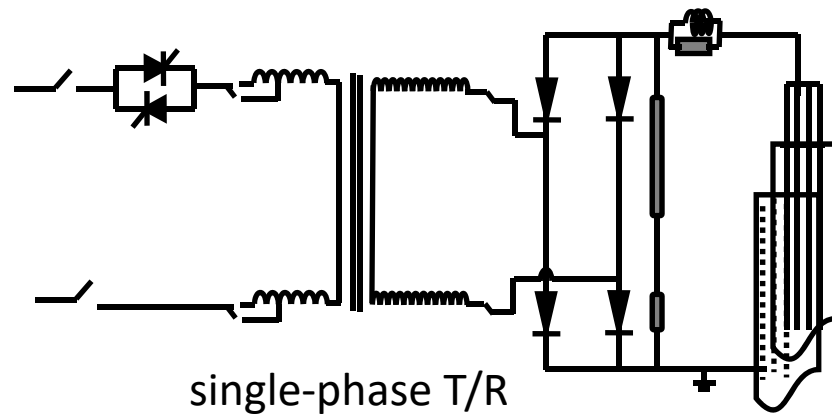
Solid waste incinerator



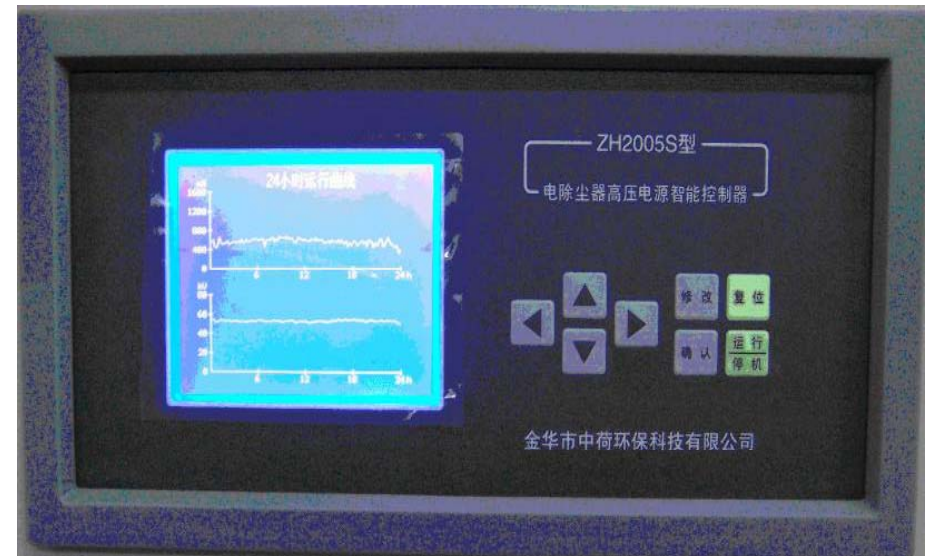
Modern ESP 600MW



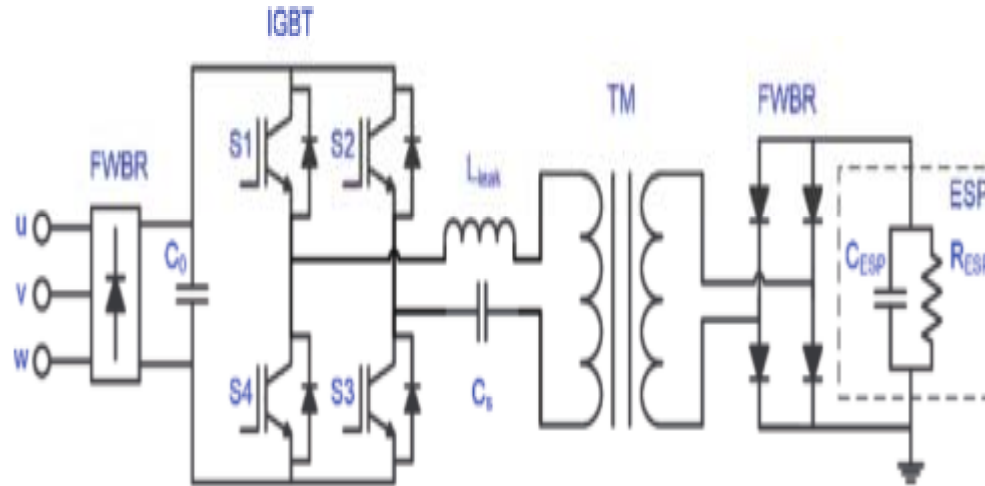
HV Power Sources



S. Li et al, J of Phys D: Applied Physics 51 (2018) 304005



HV Power Sources

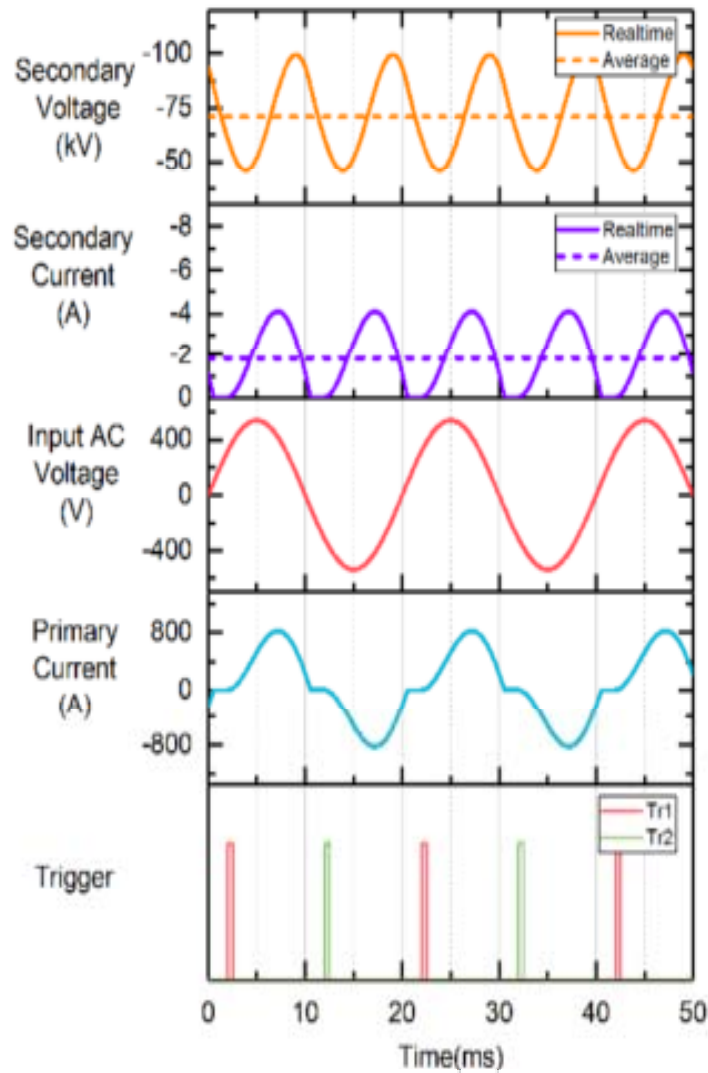


High-frequency Switch
Mode Power Source

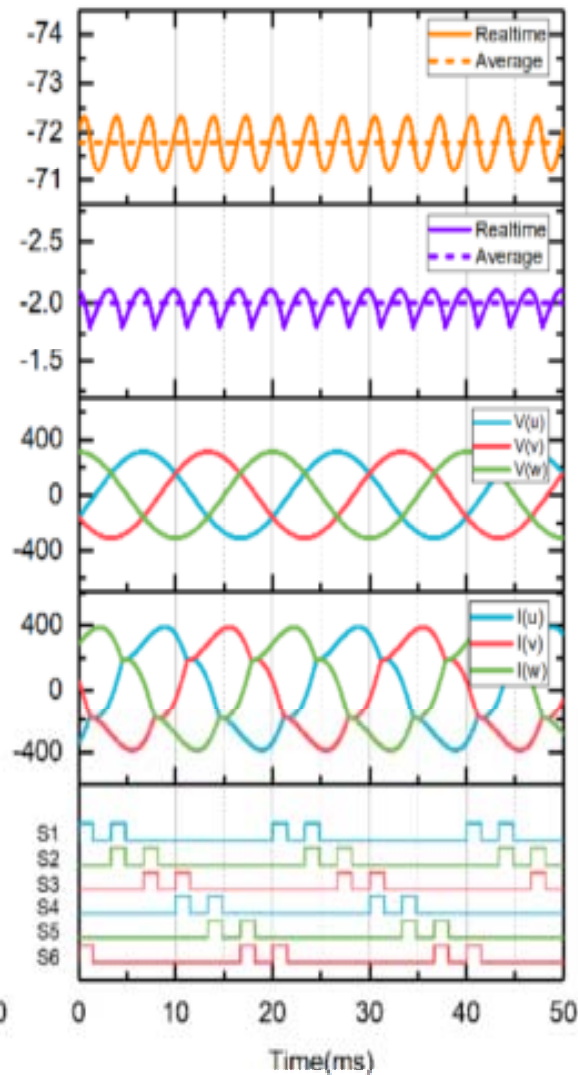
*S. Li et al, J of Phys D: Applied
Physics 51 (2018) 304005*



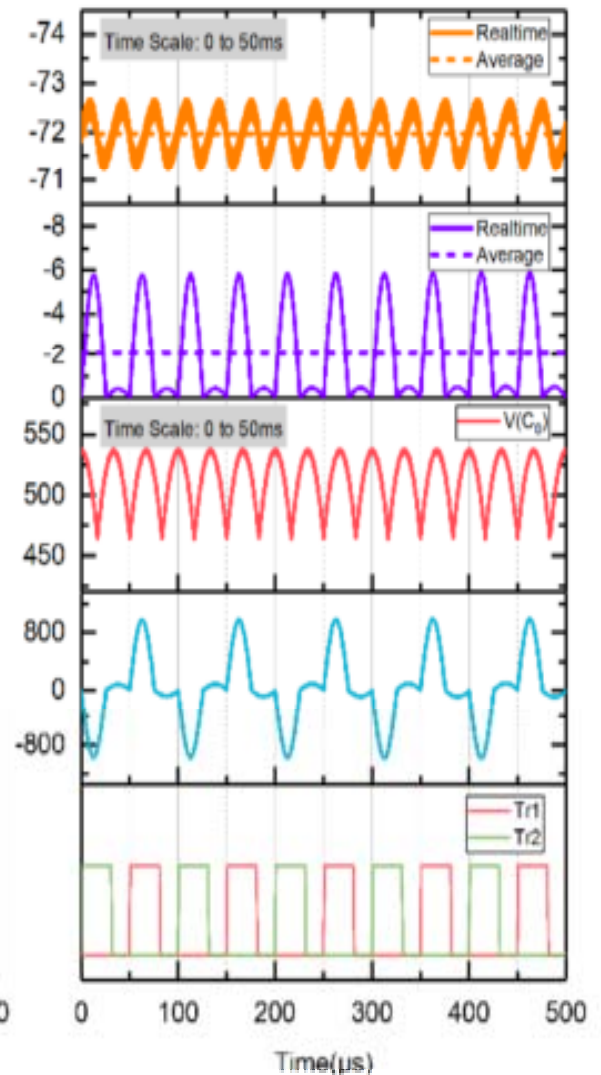
Waveforms of HV Power Sources



Single-phase



Three-phase

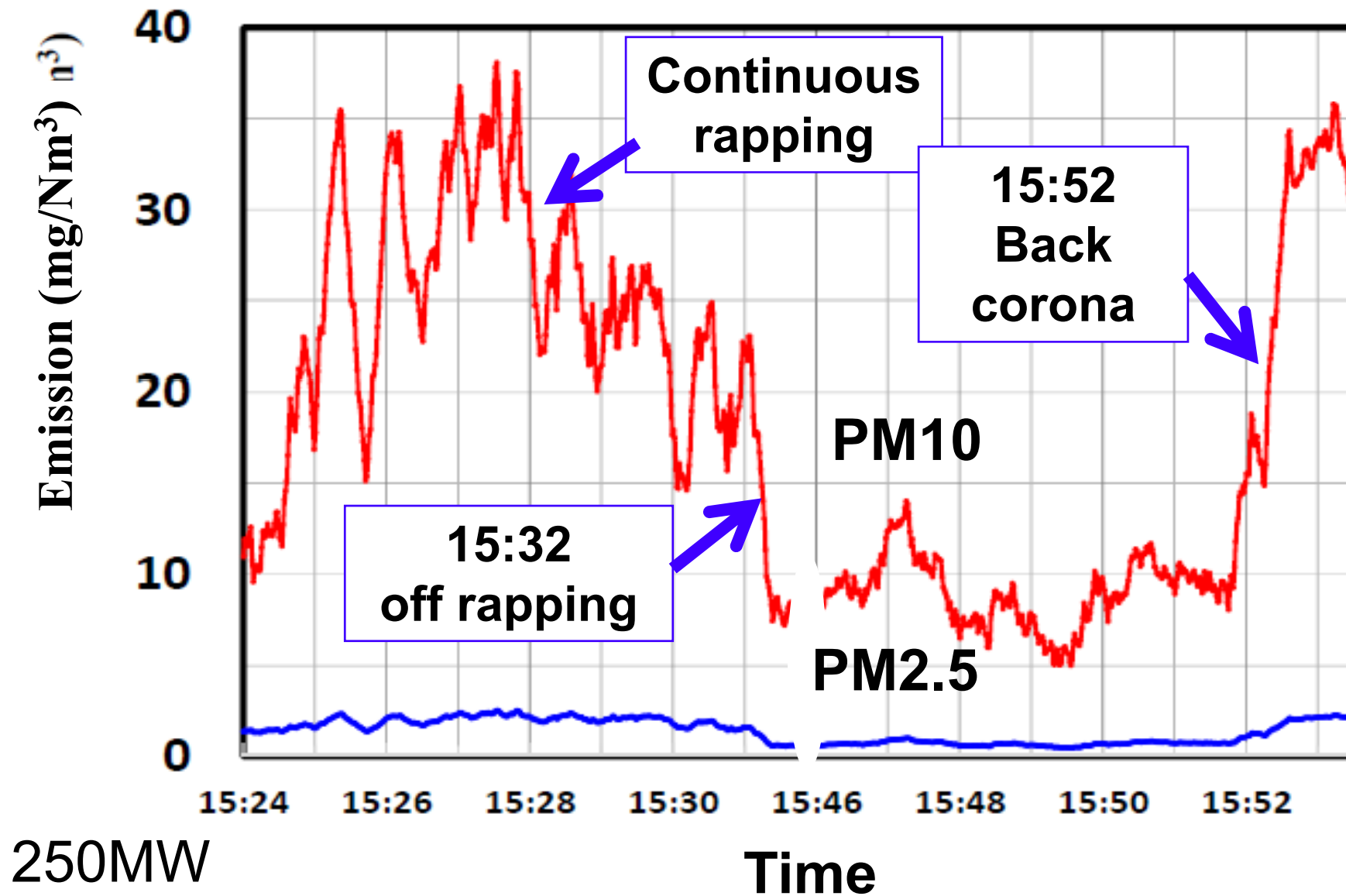


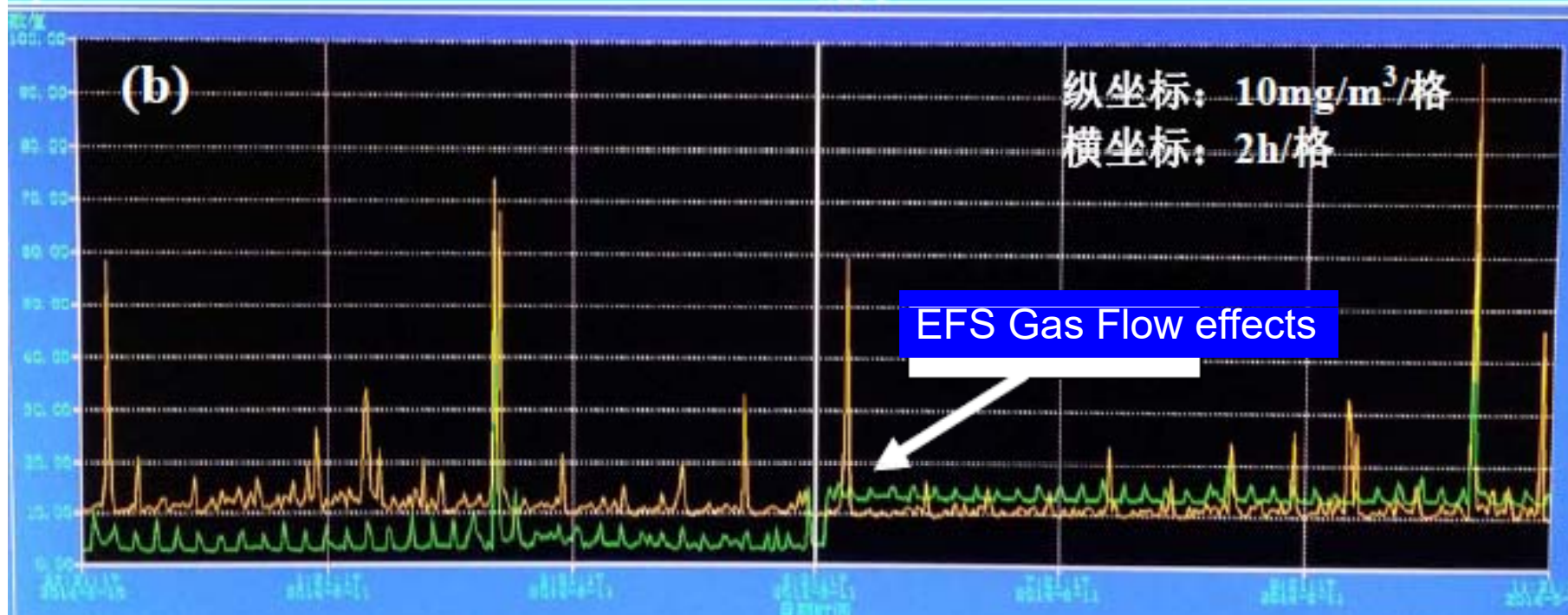
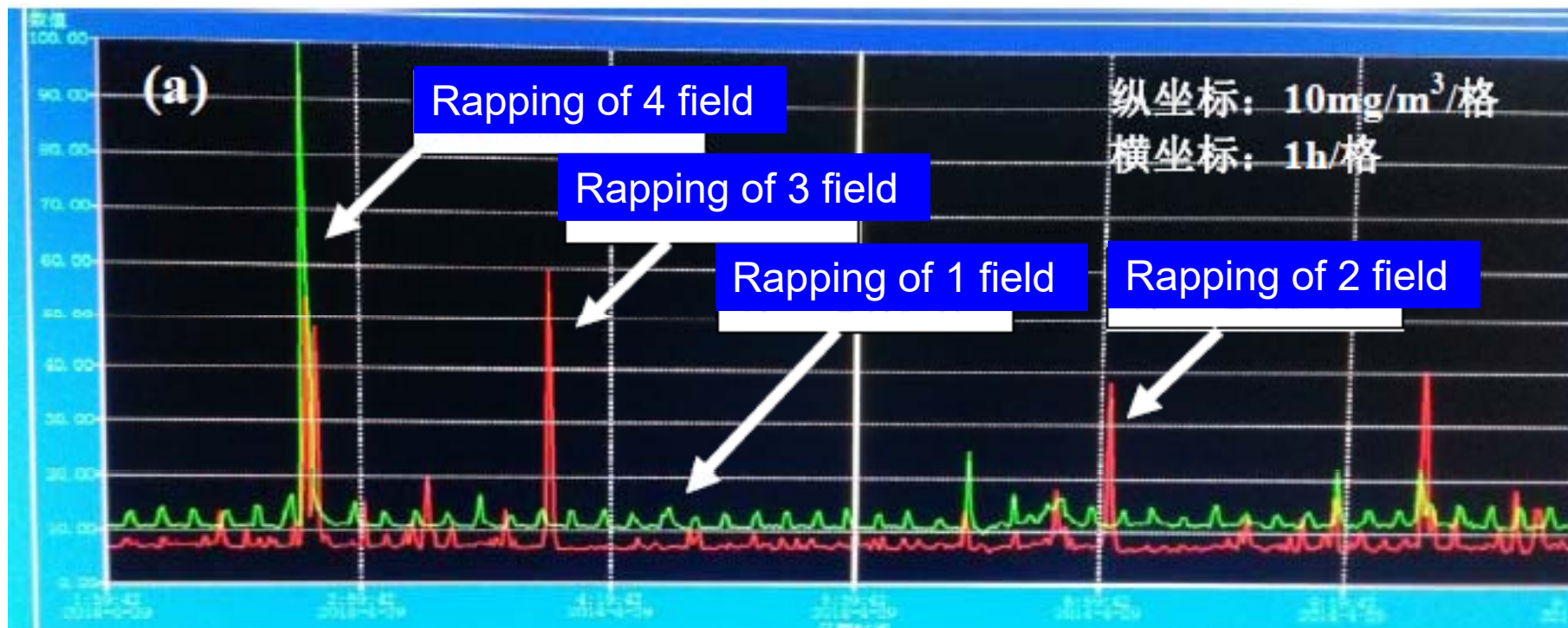
Switch-mode

Ash Collection on Electrodes

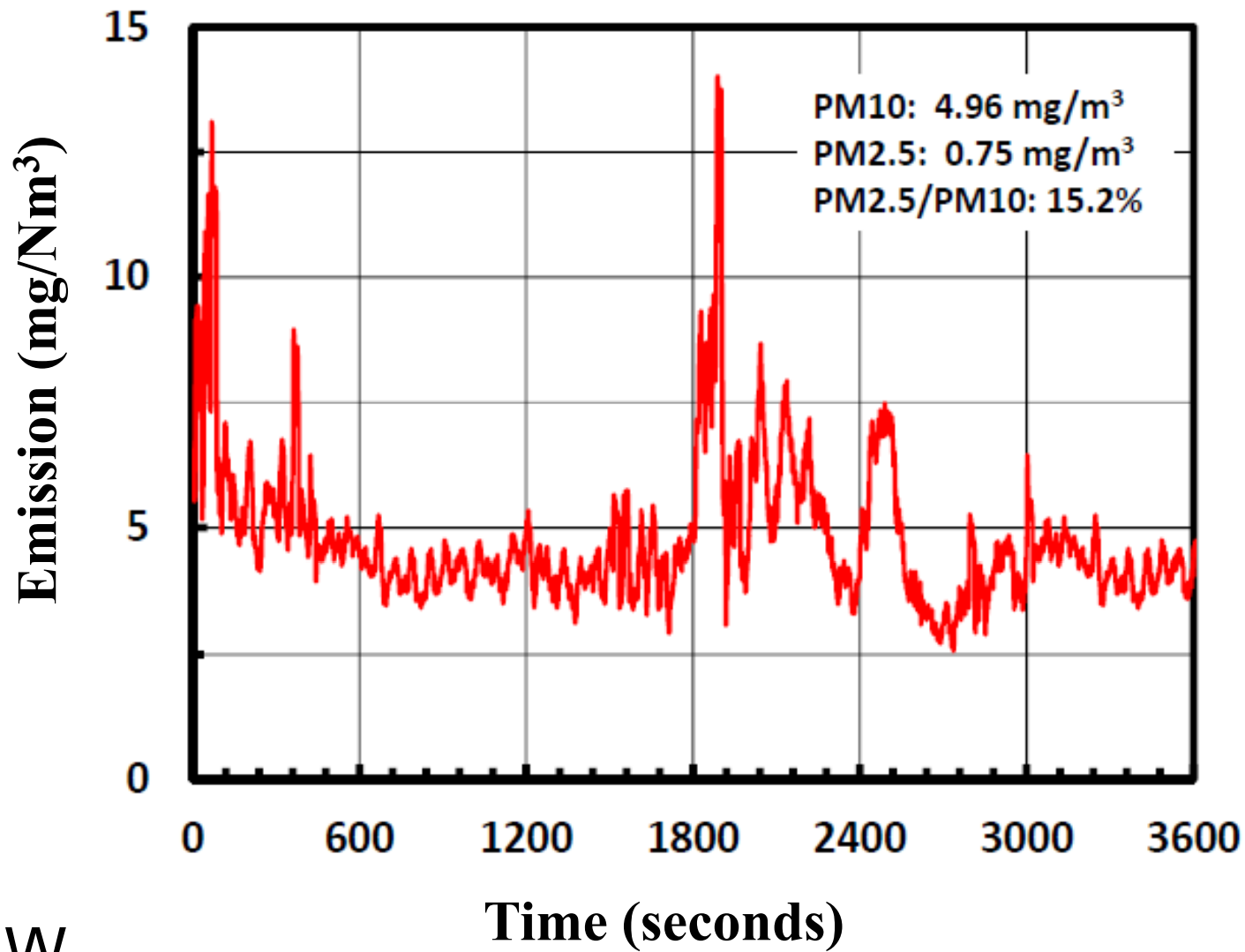


Colder Side ESP via 1st Field Rapping





PM10 Emission of Colder Side ESP



Modern Chinese ESP: 2x1100MW



Temperature: 90-120°C

Ash Inlet load: $\sim 30\text{g/m}^3$

ESP

SCA: $\sim 136\text{m}^2/\text{m}^3/\text{s}$

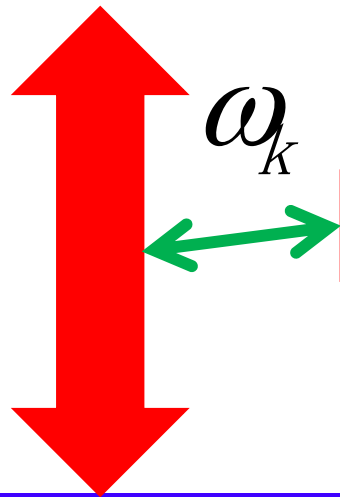
HV: 60 three-phase T/R

How to Size and Operate ESP?

Traditional Matts & Ohnfeldt's Methods

Emission

$$\ln(1 - \eta) = -(\omega_k \cdot S)^k$$



Coal or ash

$$k \approx 0.5$$

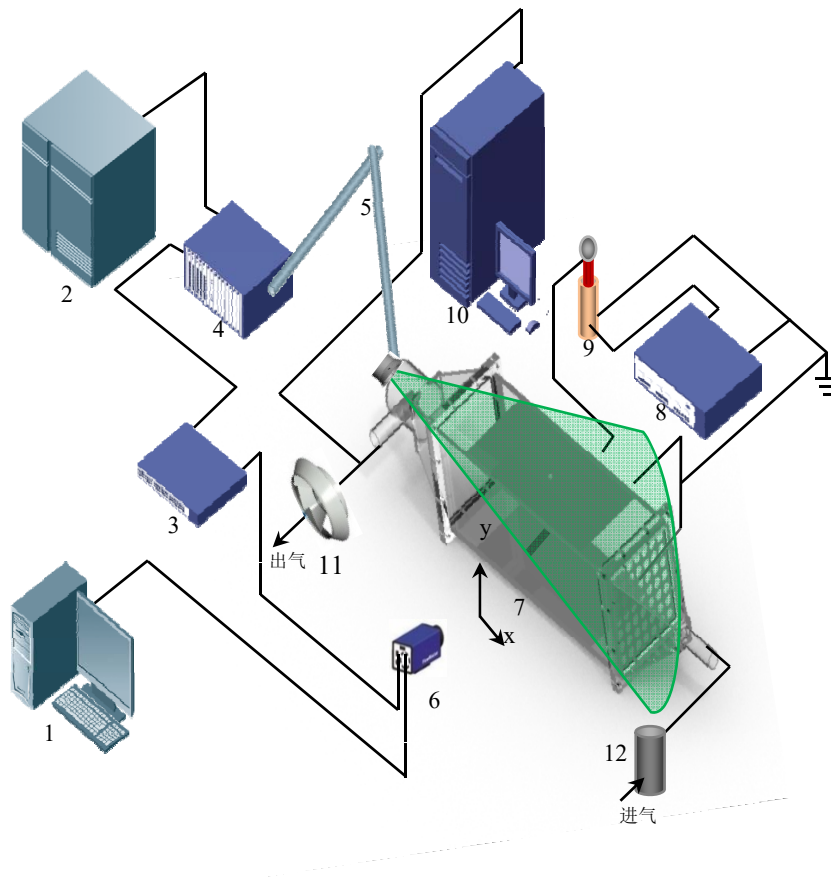
ω_k migration velocity (m/s)

S collection area (m²/m³/s)

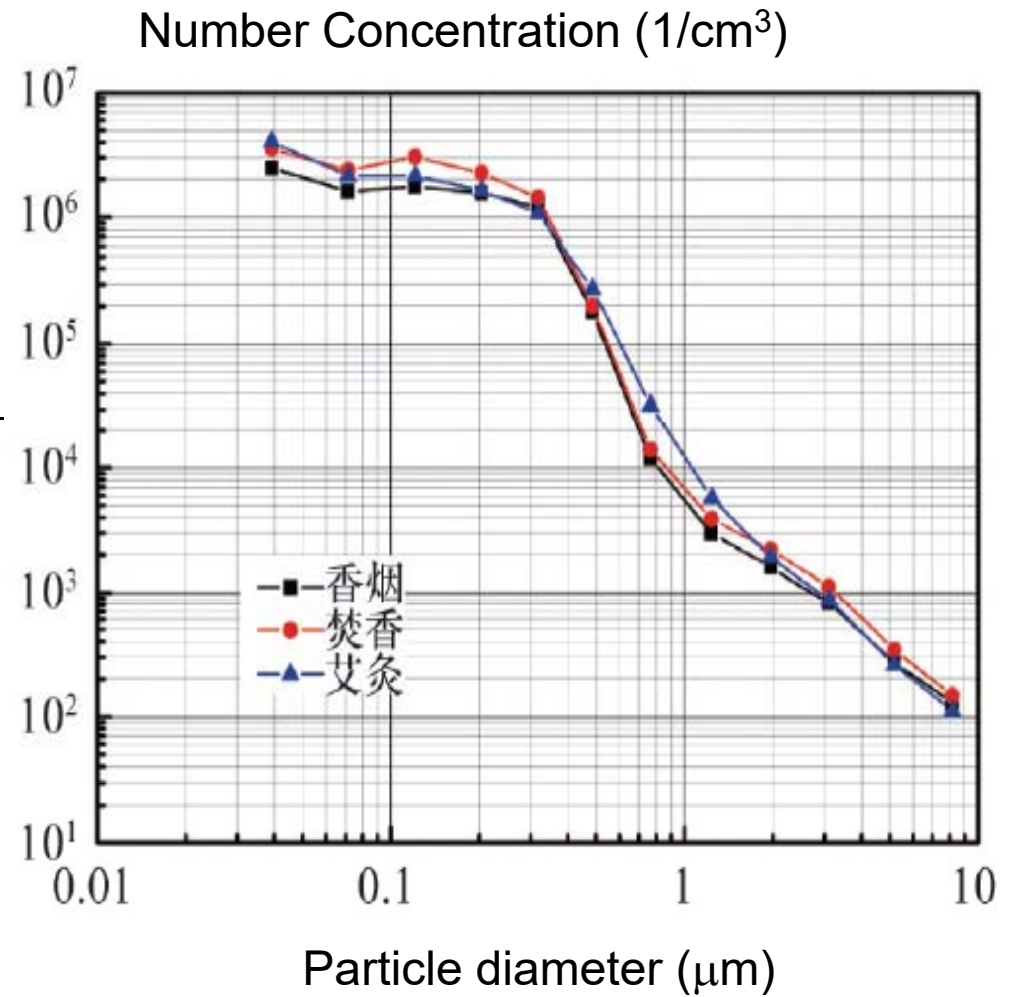
**Collection
area**

*Matts S. and Ohnfeldt P.O. (1963) Efficient gas cleaning with SF
electrostatic precipitation, SF Rev 1963-1964, 6,7, 105-22*

ESP Sizing Model and PIV Observations

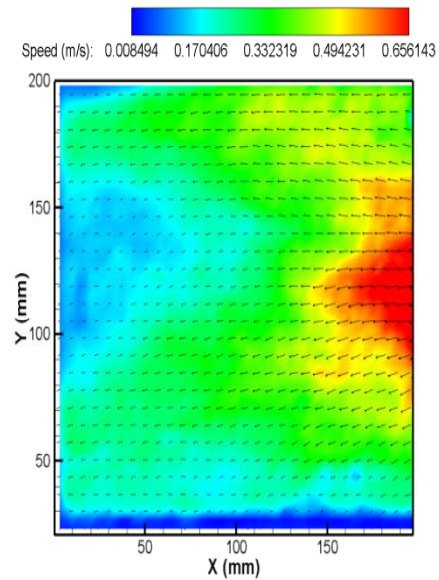


ESP: 200x200x400mm³

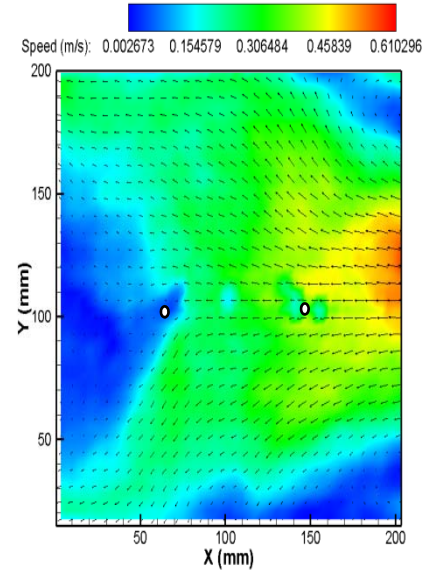


ESP Sizing and PIV

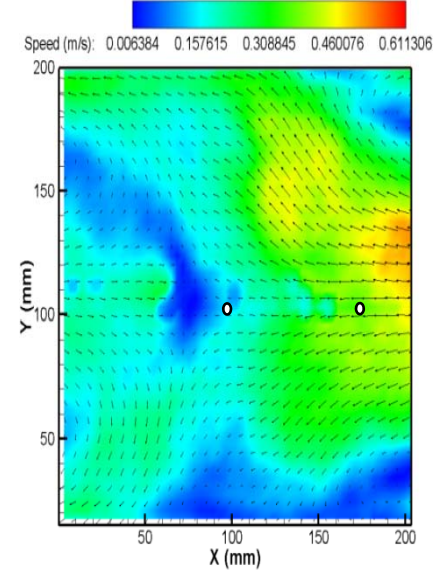
200x200mm²



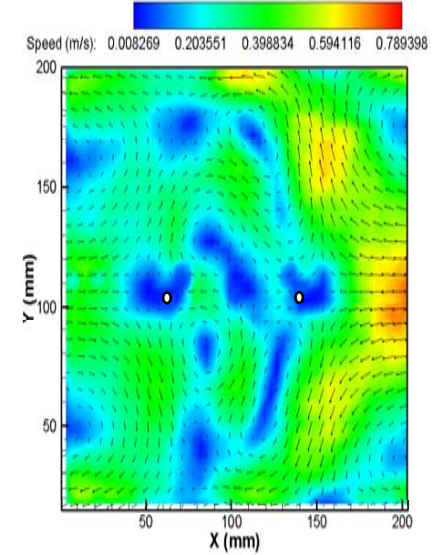
$$E^2=0$$



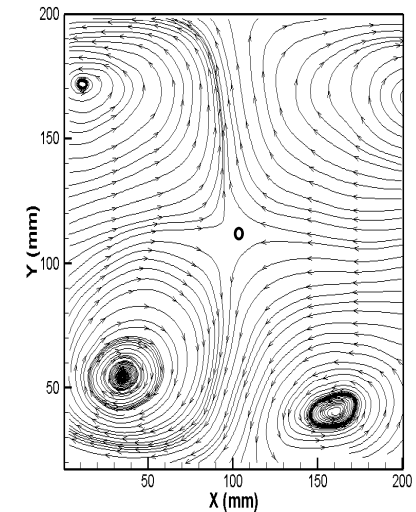
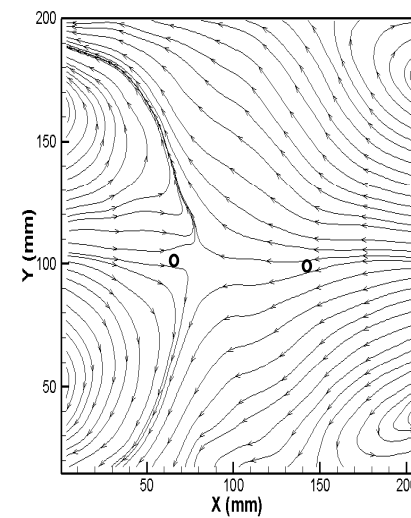
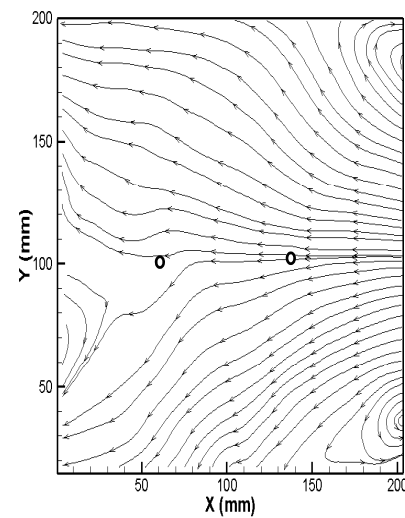
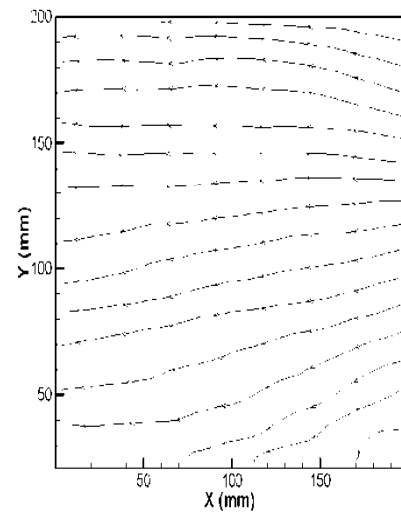
$$E^2=6(\text{kV/cm})^2$$



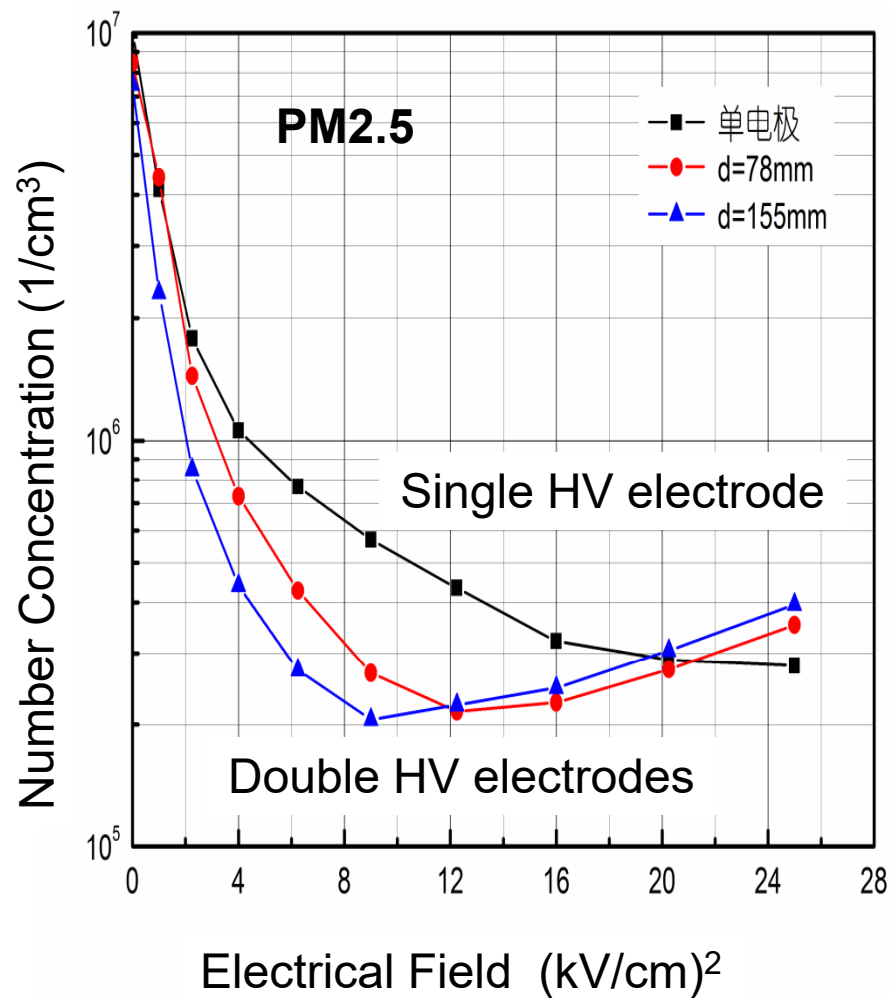
$$E^2=9(\text{kV/cm})^2$$



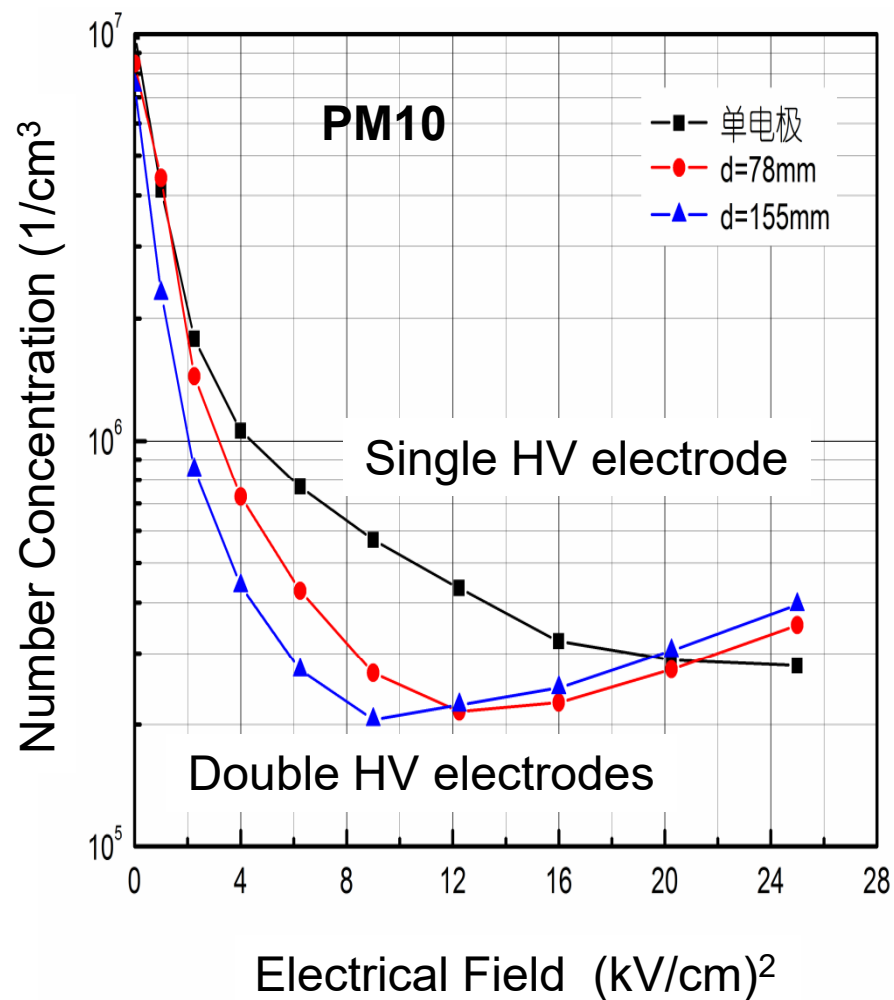
$$E^2=12(\text{kV/cm})^2$$



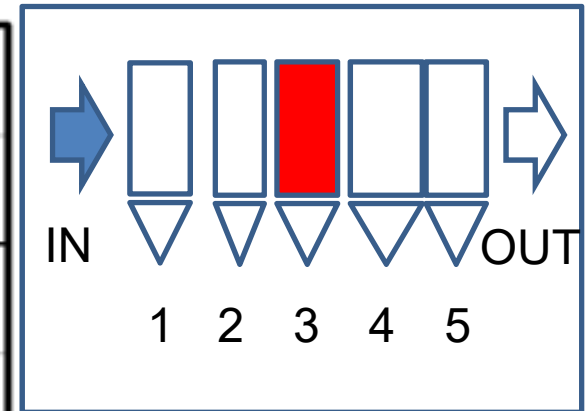
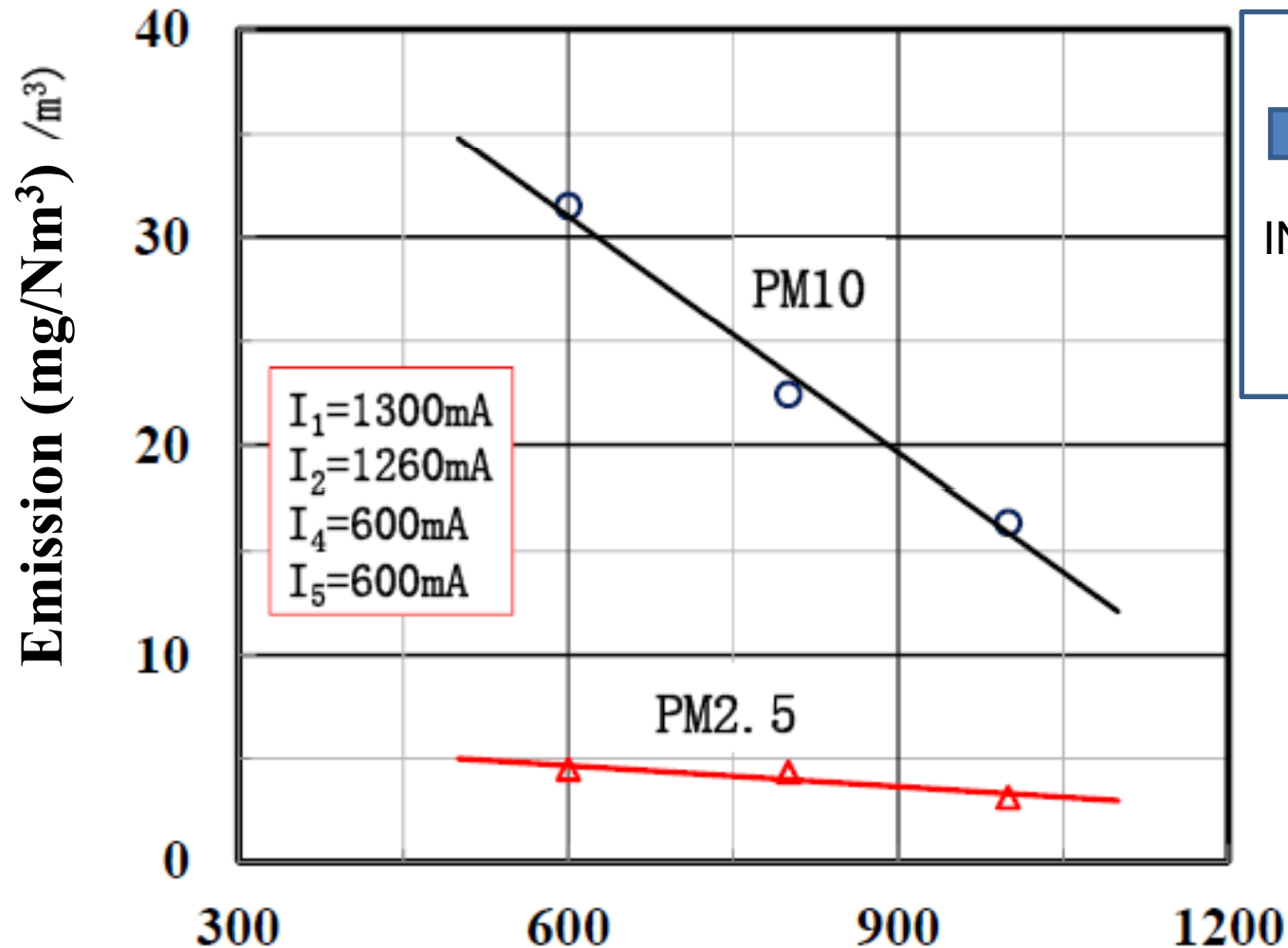
ESP Emission via Field Strength



Grade Collection via their Numbers



ESP Performance via Field Current

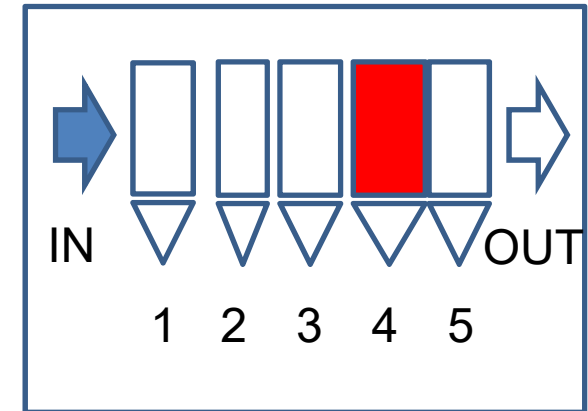
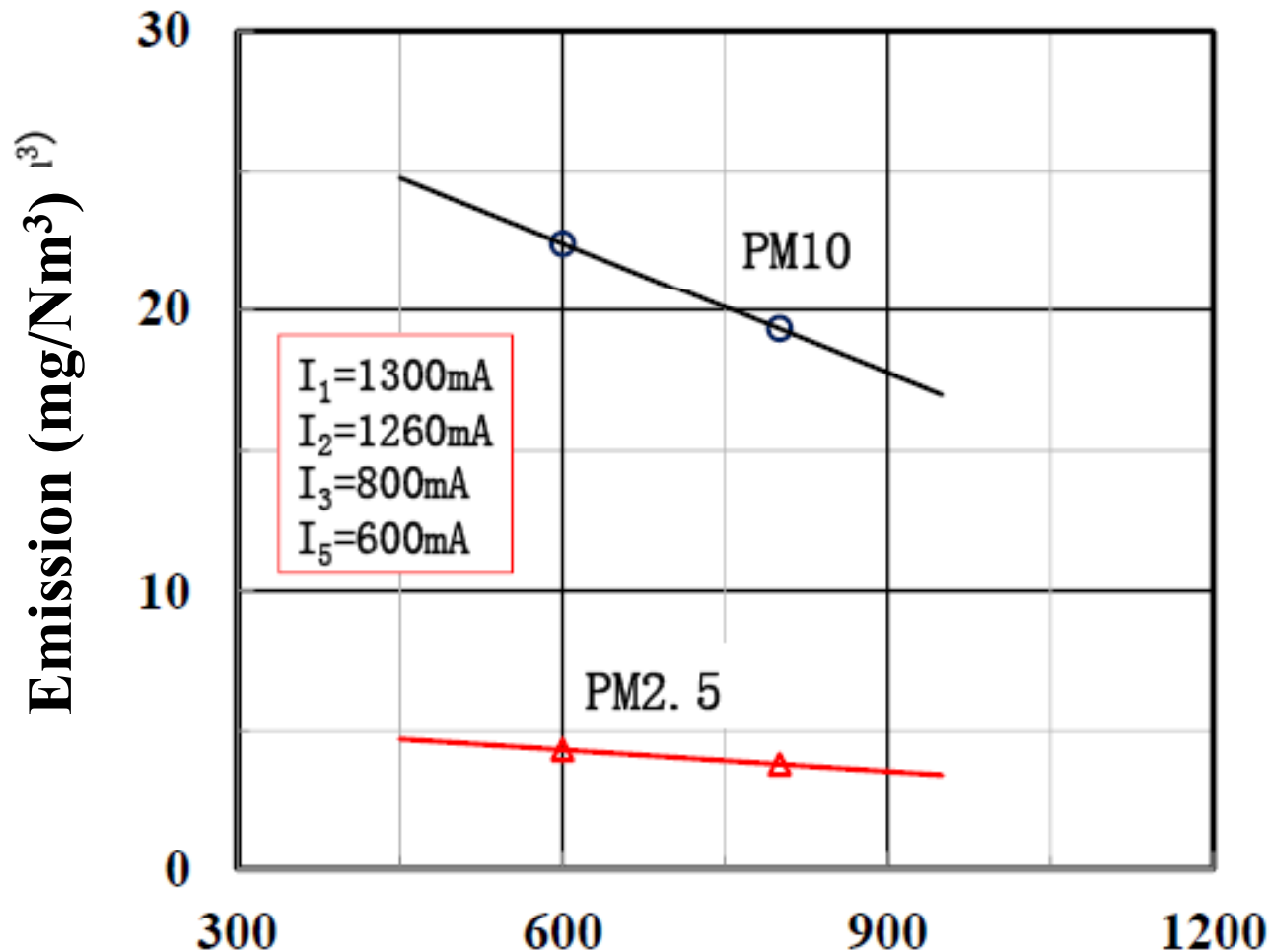


Tests with one
300MW and
five field ESP

No 3 field secondary current (mA)

Huang Y. et al,
IJPEST 2015

ESP Performance via Field Current

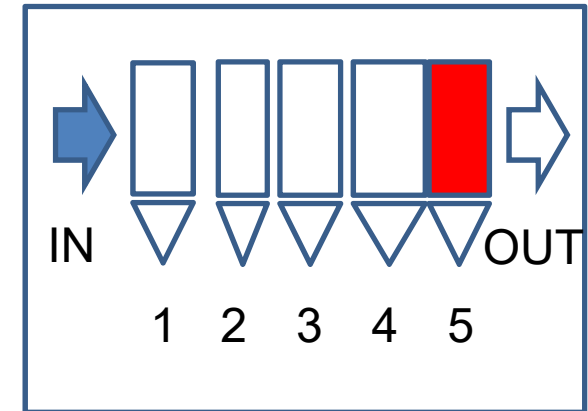
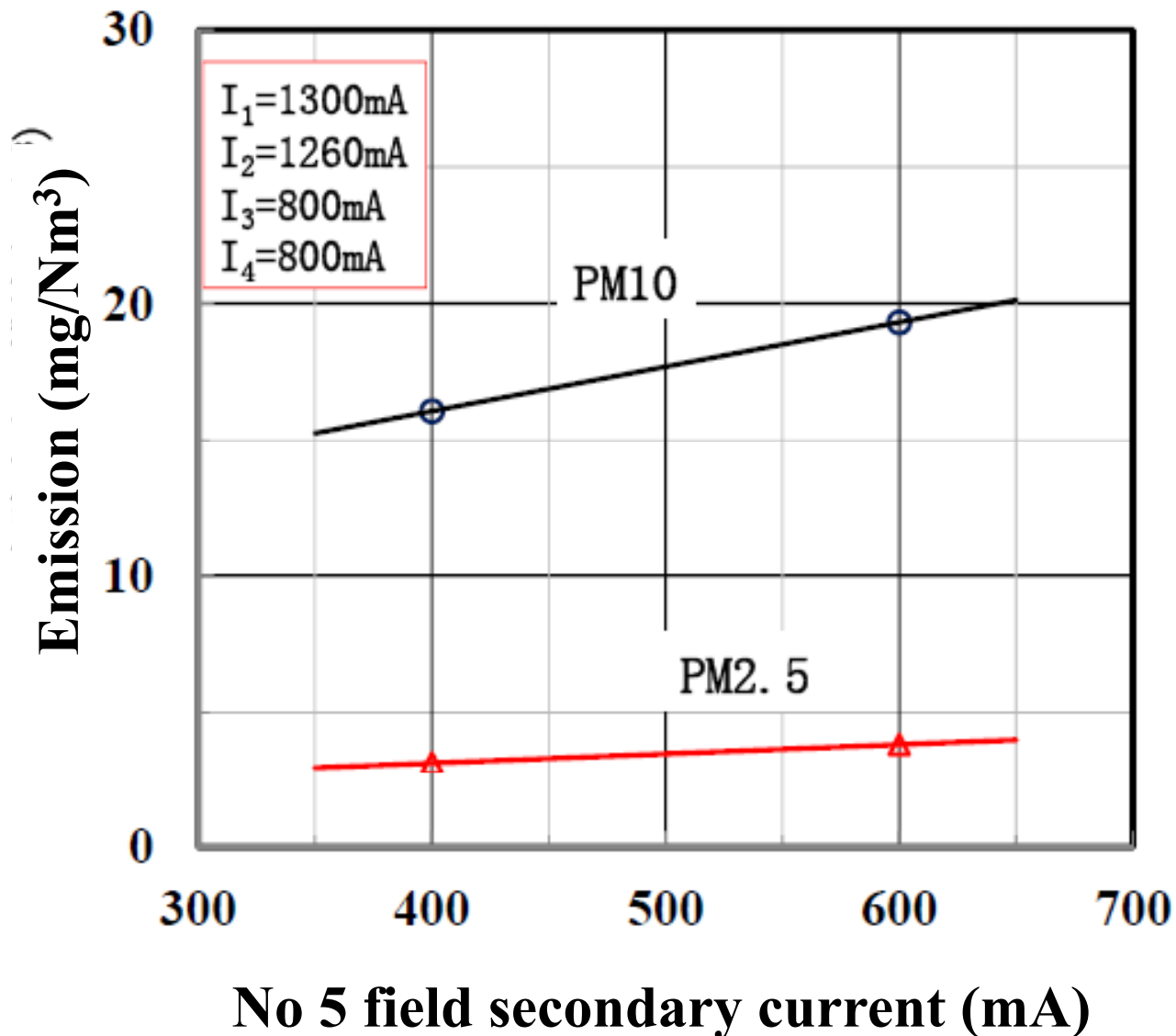


Tests with one
300MW and
five field ESP

No 4 field secondary current (mA)

Huang Y. et al,
IJPEST 2015

ESP Performance via Field Current



Tests with one
300MW and
five field ESP

Huang Y. et al,
IJPEST 2015

How to Size and Operate ESP?

ESP Index Methods

$$\lg \frac{m}{\beta \cdot M_0} = -\alpha \cdot E_a \cdot E_p \cdot S$$

COAL

HV Power

Electrodes

Rapping

PM concentration

Temp

Power
source

$$E_a \cdot E_p$$

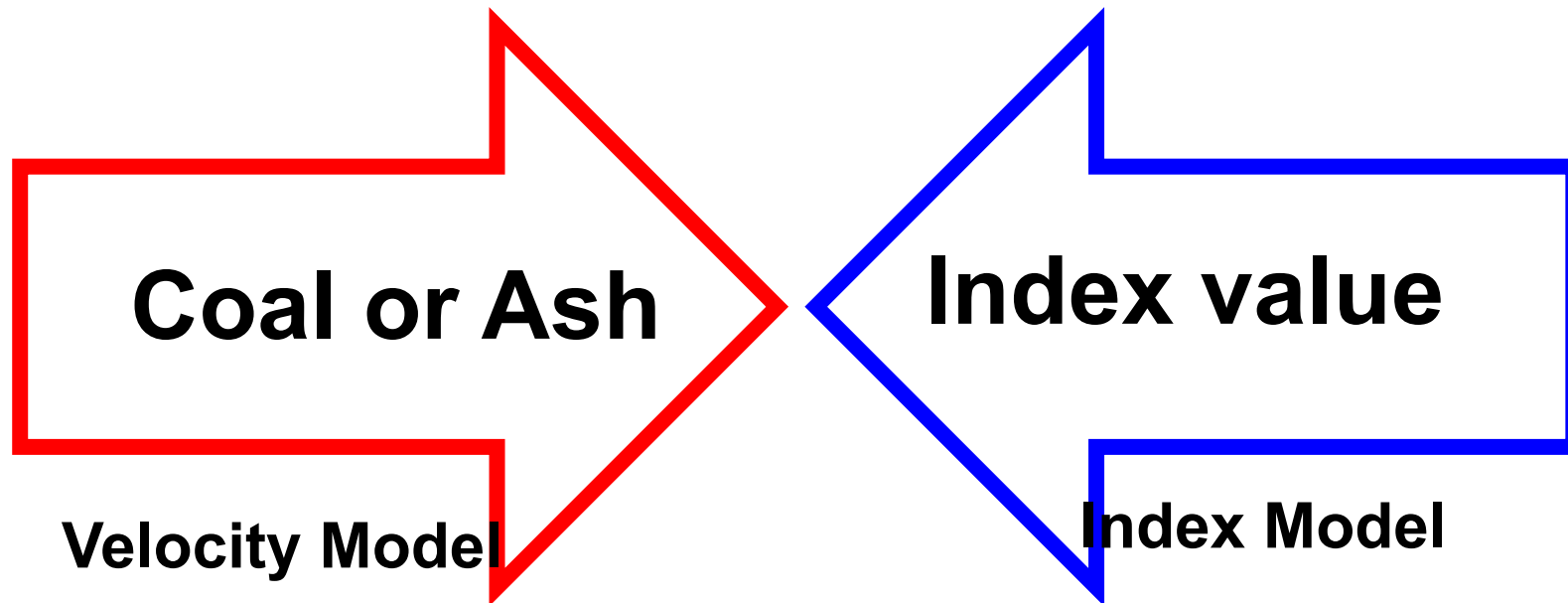
Specific
Area
S

ESP Size

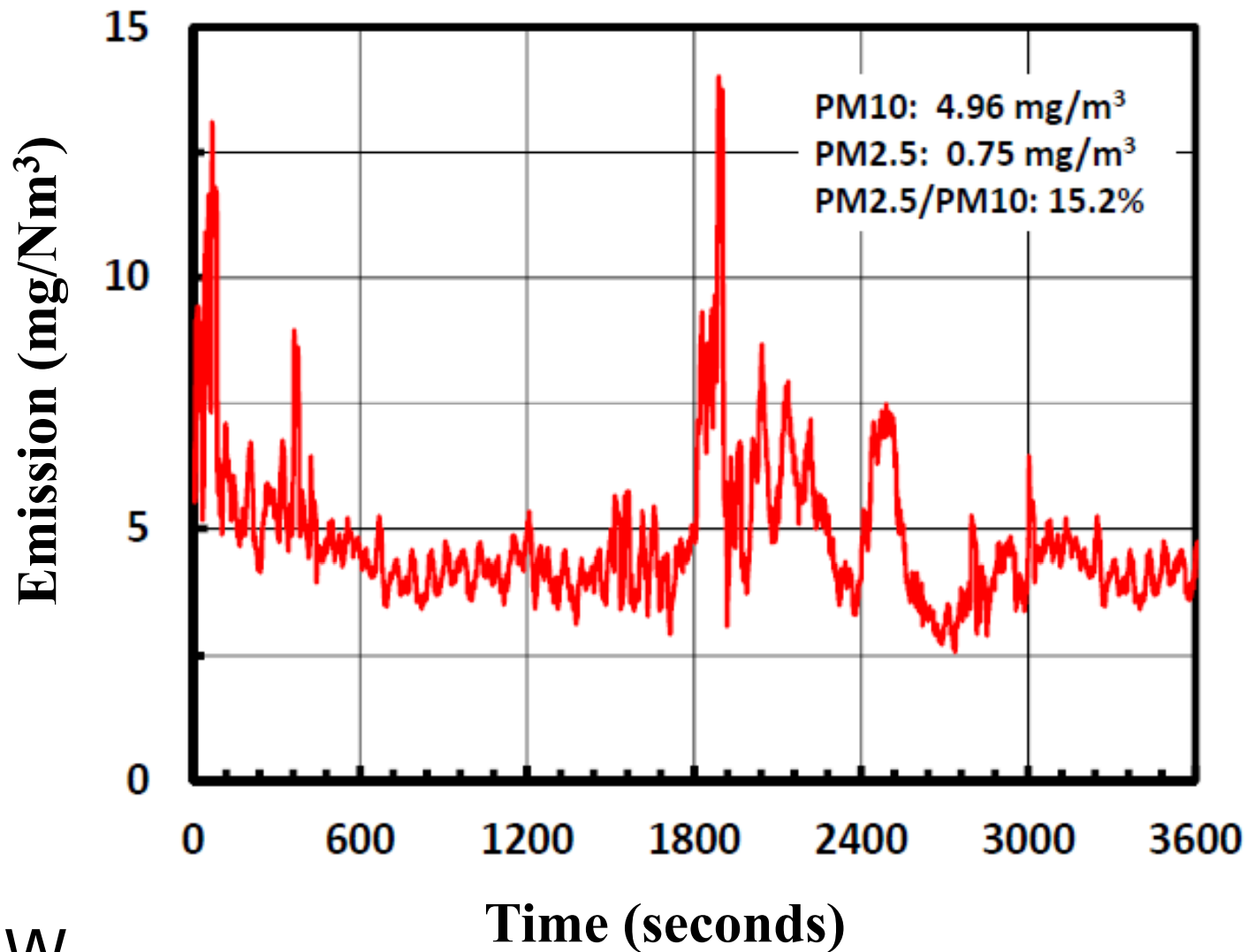
Gas flow rate

How to Size and Operate ESP?

From Migration Velocity to the Index Value



PM10 Emission of Colder Side ESP



Modern Chinese ESP: 2x1100MW



Temperature: 90-120°C

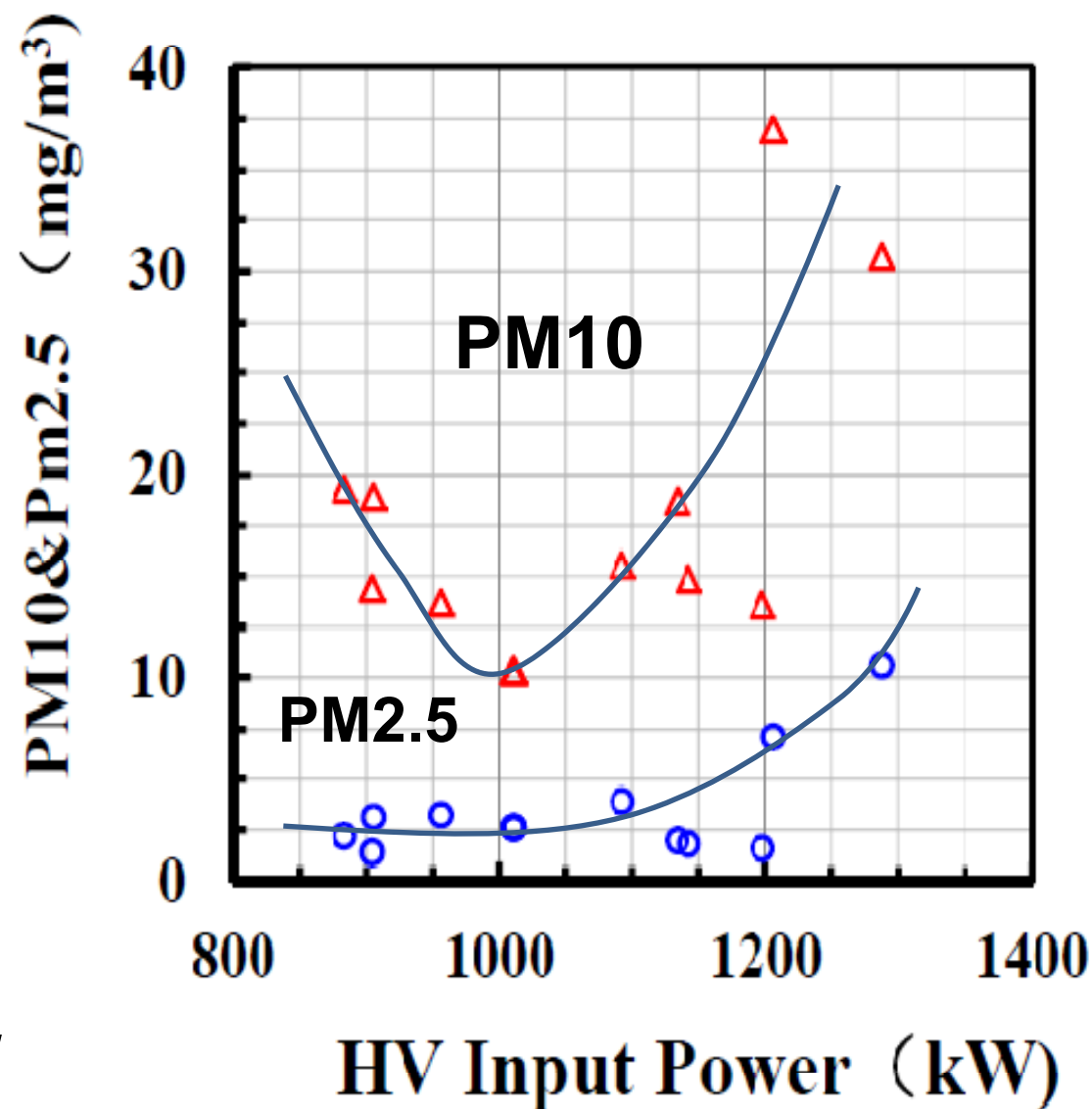
Ash Inlet load: $\sim 30\text{g/m}^3$

ESP

SCA: $\sim 136\text{m}^2/\text{m}^3/\text{s}$

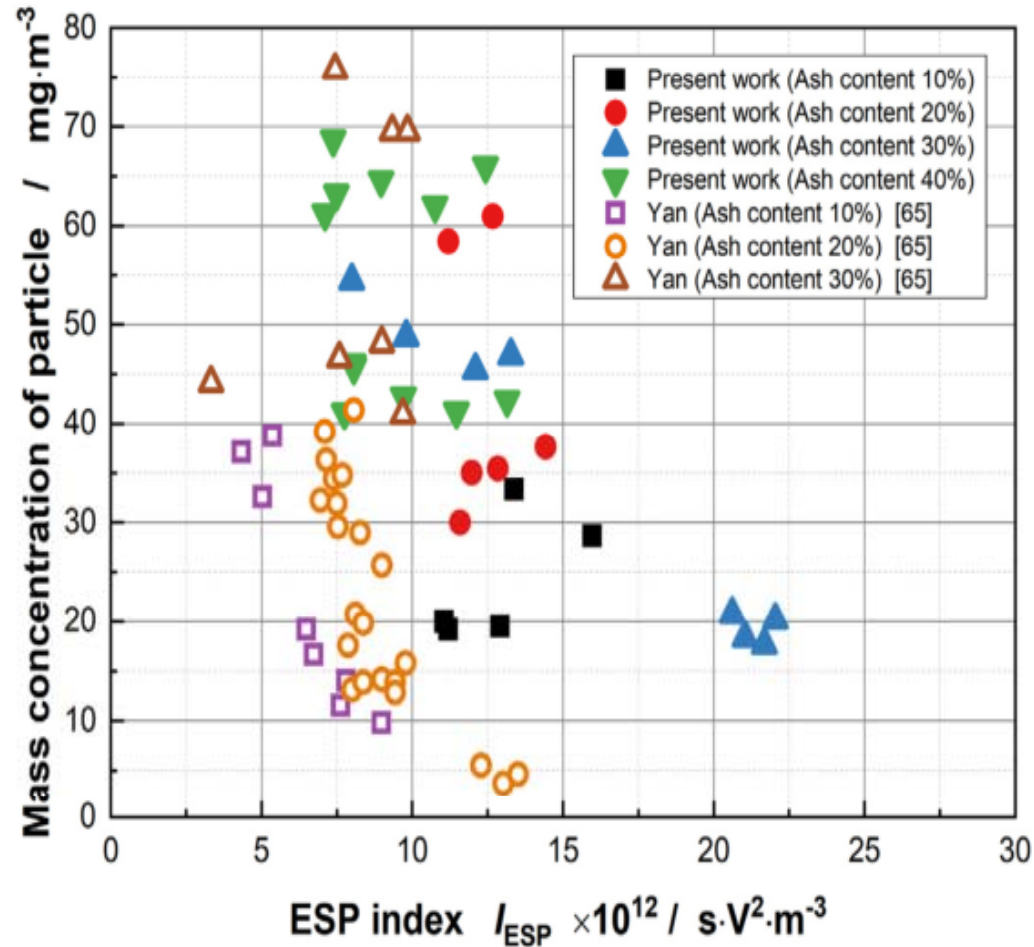
HV: 60 three-phase T/R

PM2.5&PM10 via the HV Input Power



2x660MW

ESP Outlet PM Emission

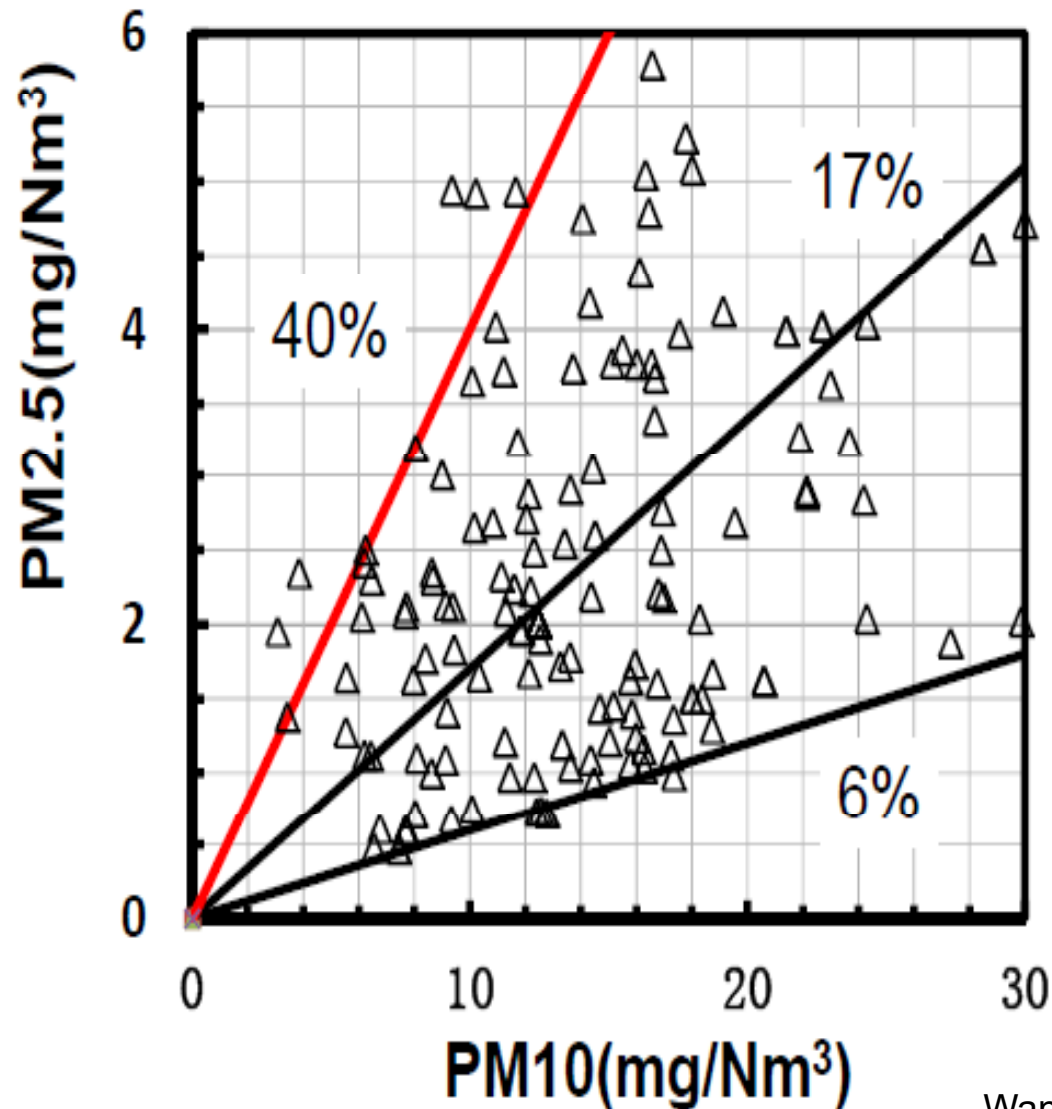


$$\lg \frac{m}{\beta \cdot M_0} = -\alpha \cdot E_a \cdot E_p \cdot S$$

Since 2013, we have upgraded more than 130 industrial ESPs for reducing emission and saving energy costs

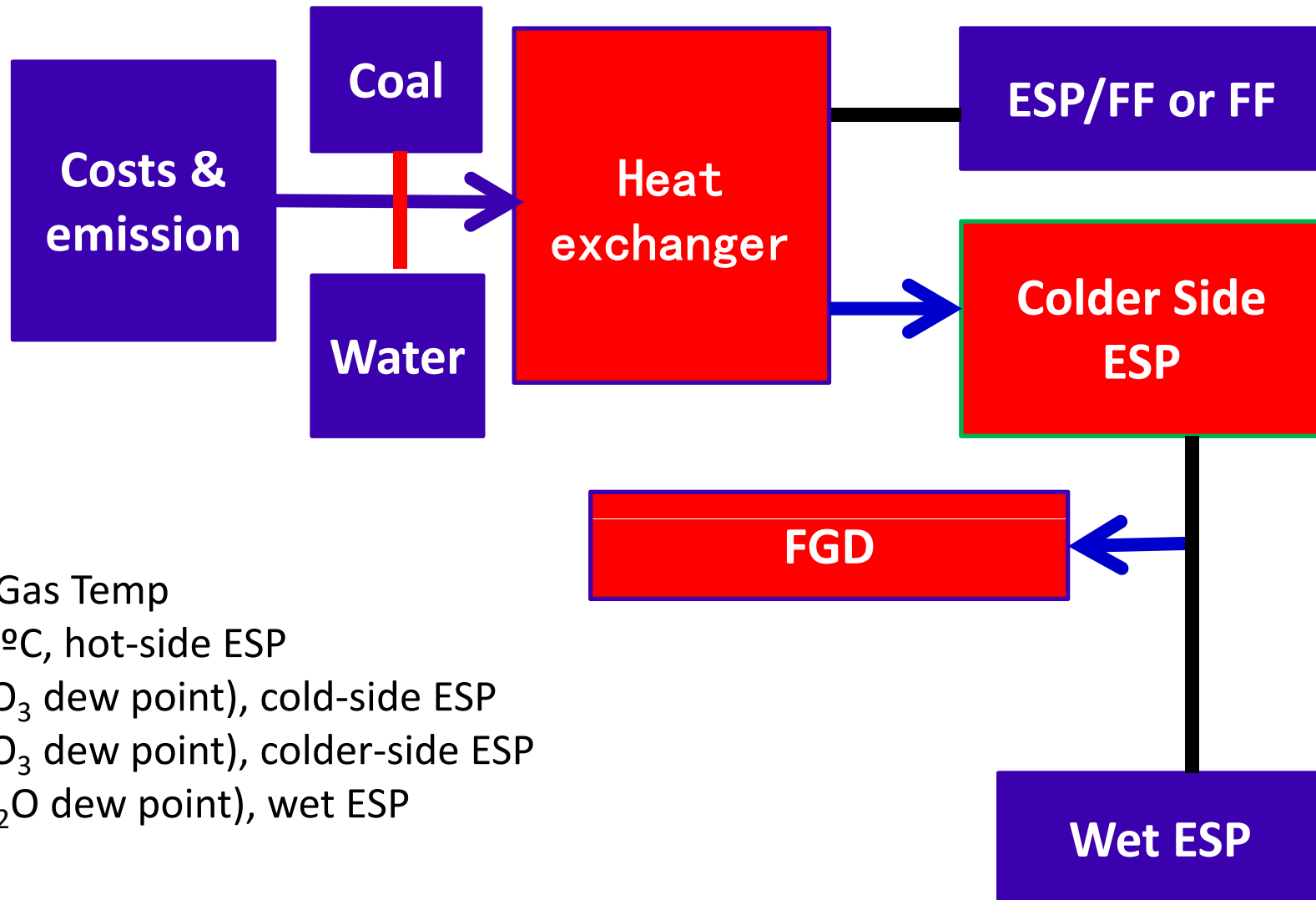
*S. Li et al,
Powder Technology 347
(2019) 170-178*

PM2.5 via PM10 at ESP Outlets



2013-2017
24 of
600-1000MW
35 of
200-350MW
14 of
125-150MW
15 of
75-220T/h

Near Zero Emission Control



ESP & Gas Temp

$T > 300^{\circ}\text{C}$, hot-side ESP

$T > T(\text{SO}_3 \text{ dew point})$, cold-side ESP

$T < T(\text{SO}_3 \text{ dew point})$, colder-side ESP

$T < T(\text{H}_2\text{O dew point})$, wet ESP

Application: 75t/h Boilers – HV sources

Before



After
ESP
Upgrading



Modern ESP Design

How to run these HV power sources?

125-200 MW Boiler:

2x4 or 2x5 bus sections

8 or 10 HV power sources

1200mA&82kV

300-660 MW Boiler:

4x4 or 4x5 bus sections

16 or 20 HV power sources

1200mA (2000mA) &82kV

1000-1100 MW Boiler:

6x4 or 6x5 bus sections

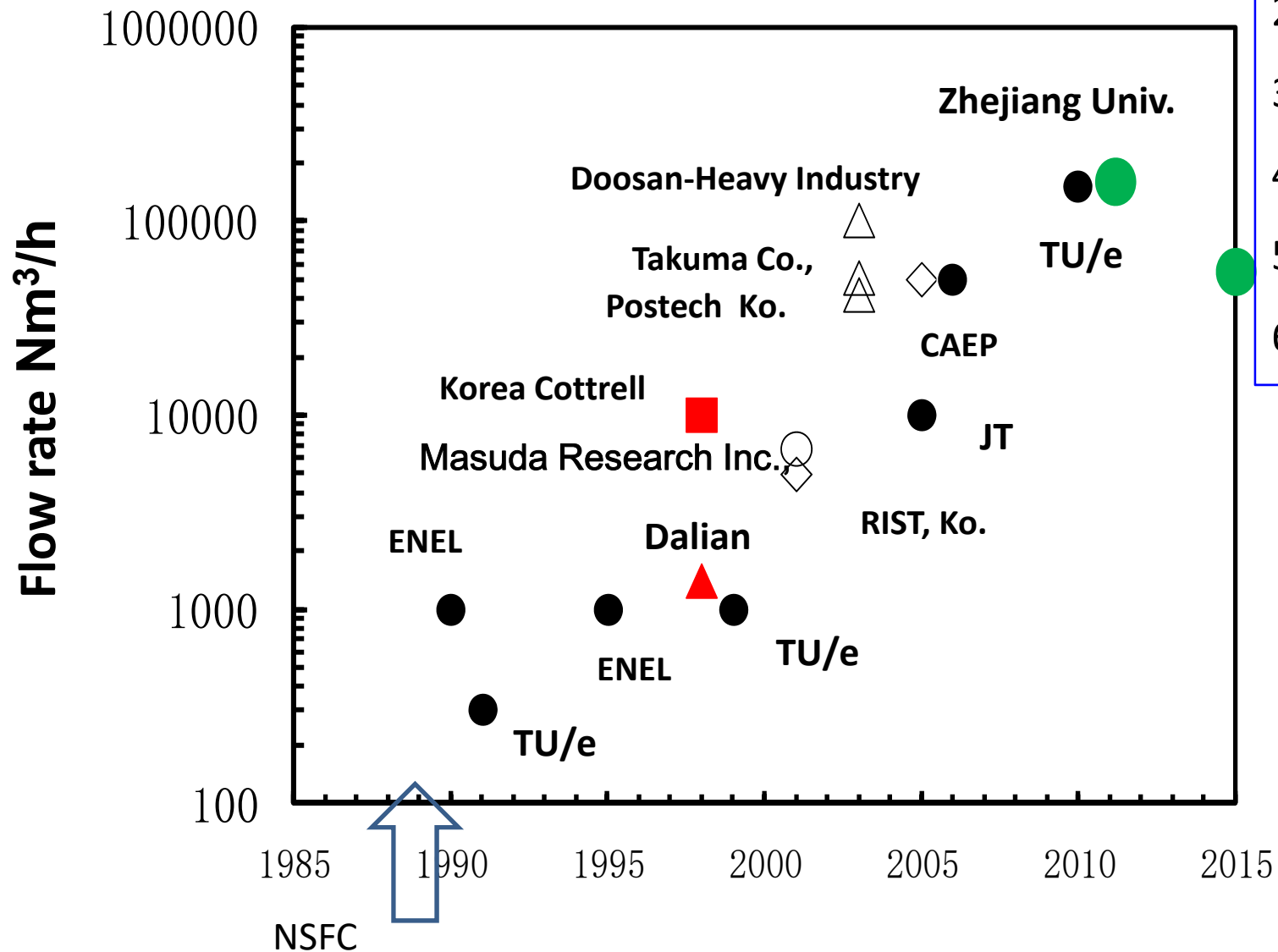
24 or 30 HV power sources

2000mA &82kV

New one: 2x3x10 bus sections



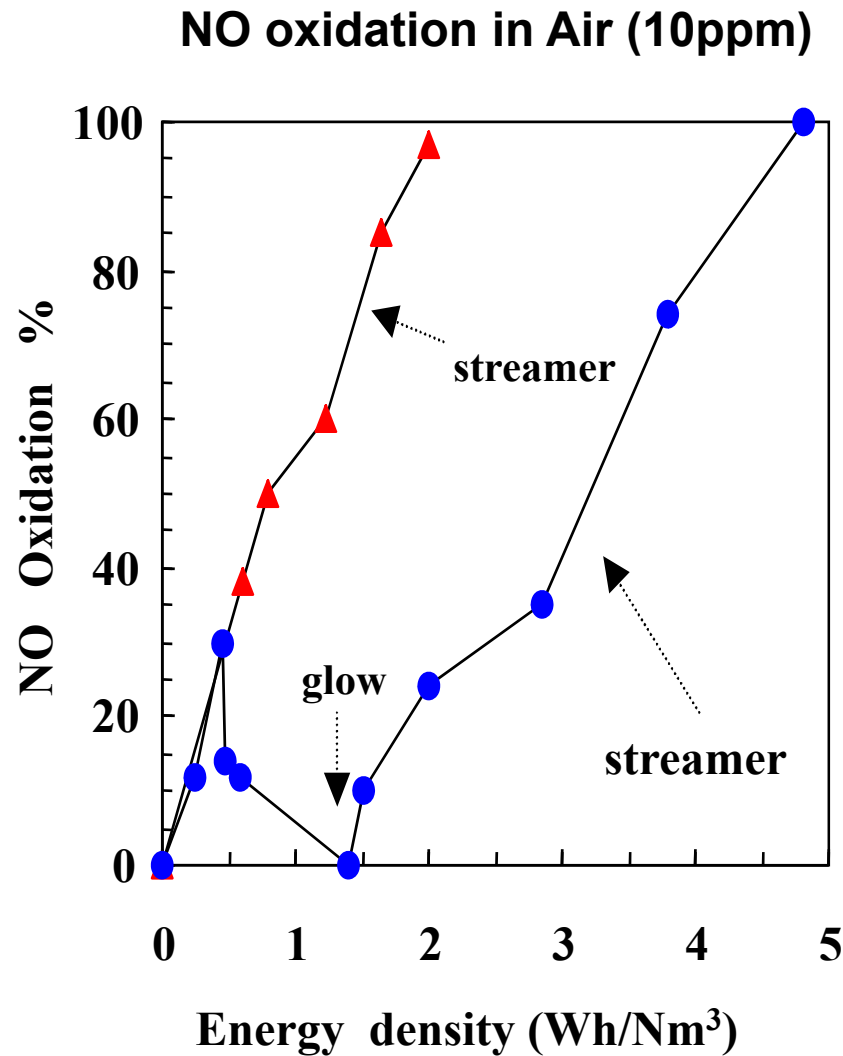
Some NTP Demonstrations



2017

1. 300MW
2. 600MW
3. 90t
4. 130t
5. 220t
6. 450t

Discharge Modes and Chemical Reactivity



Positive corona discharge in air



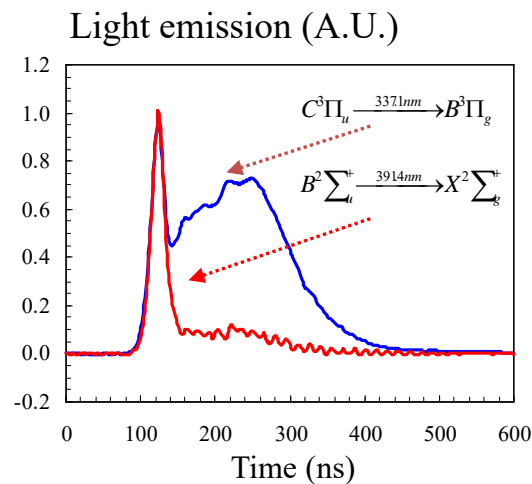
Reactions: Streamer

Charging: glow or streamer

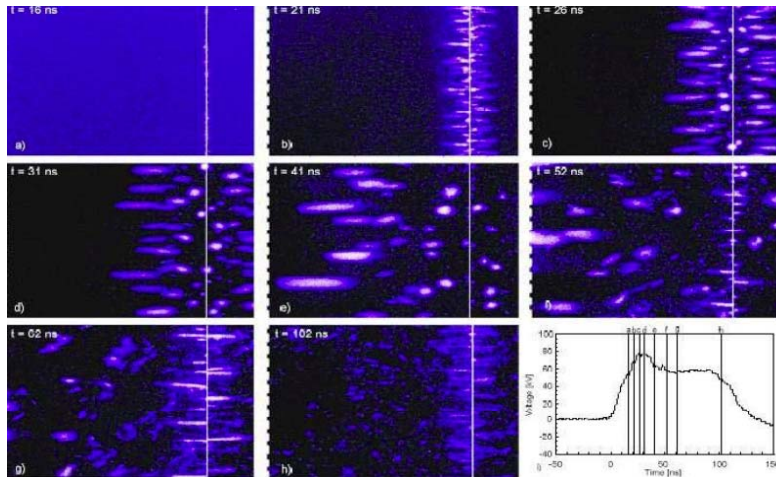
Electrical Discharges and Processes

Streamer Corona

SNTP

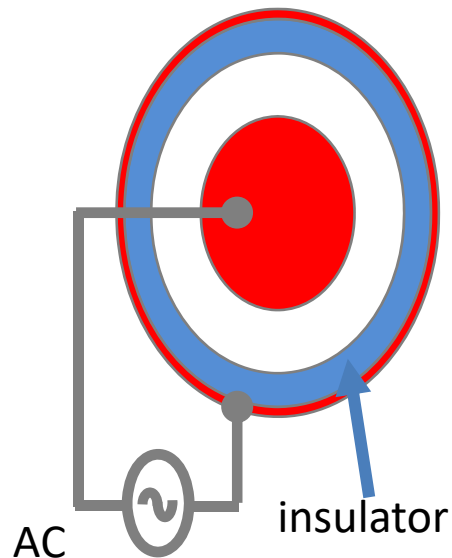


K. Yan, et al, ISPC
1993



G.J.J. Winands, et.al., J. Phys. D: Appl. Phys. 39 (2006) 3010–3017

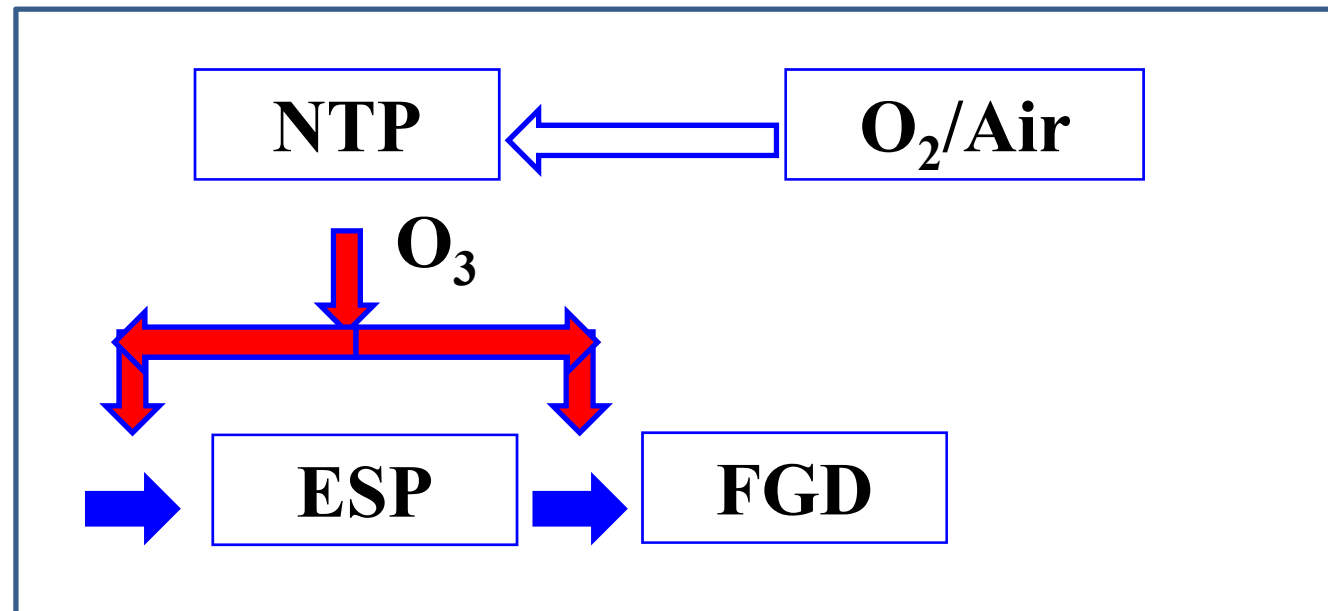
Dialectical Barrier Discharge DNTP



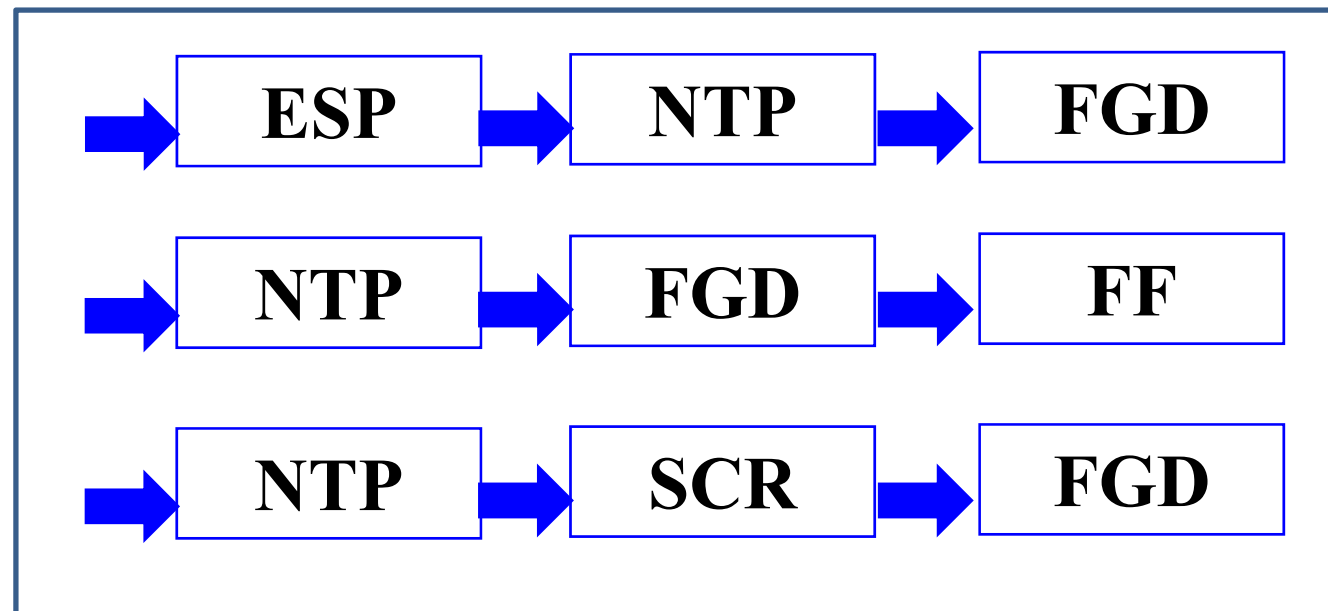
200-400kVA
Introduced to market in 2017

NTP for DeNO_x & DeSO₂ & PM

Indirect



Direct



O₃ Oxidation NO - FGD

$$3 \times 130t + 2 \times 220t + 1 \times 450t = 1280 t$$

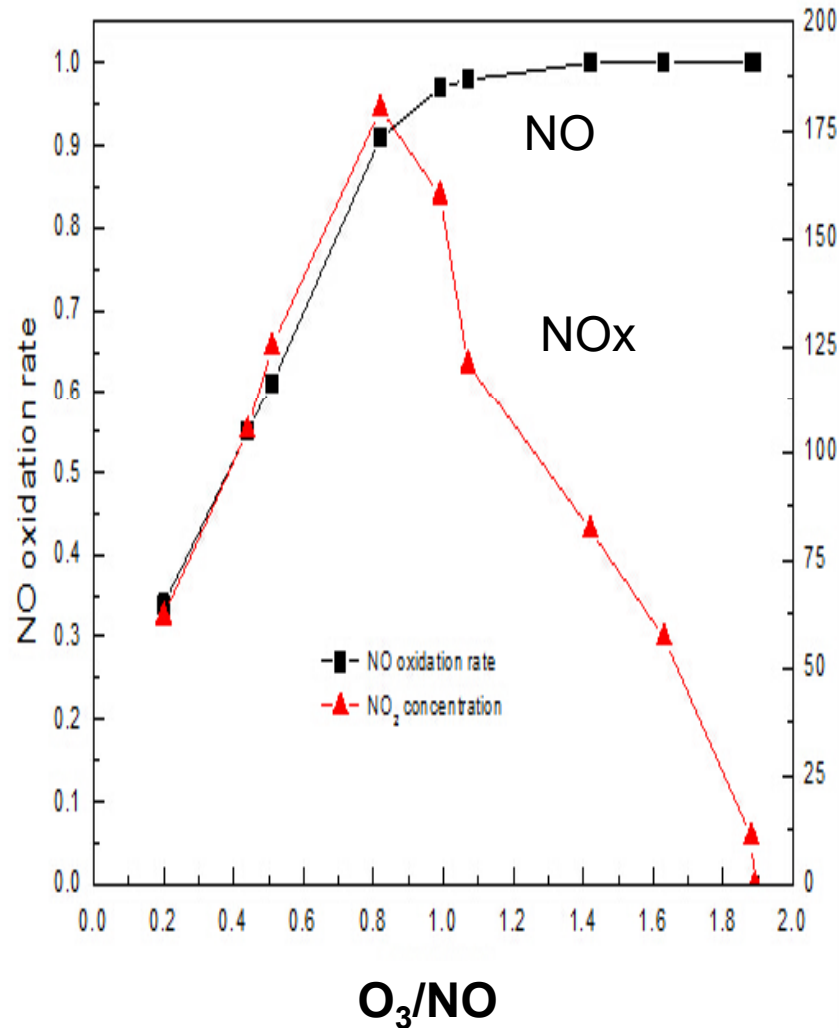
1. ESP+O₃+FGD
2. O₃: 240kg/h
3. NO_x efficiency $\geq 70\%$
4. O₃/NO: 1.2-1.4
5. NO_x $\leq 50\text{mg/m}^3$
6. P ~ 2600 kVA
7. O₂: 2400kg/h



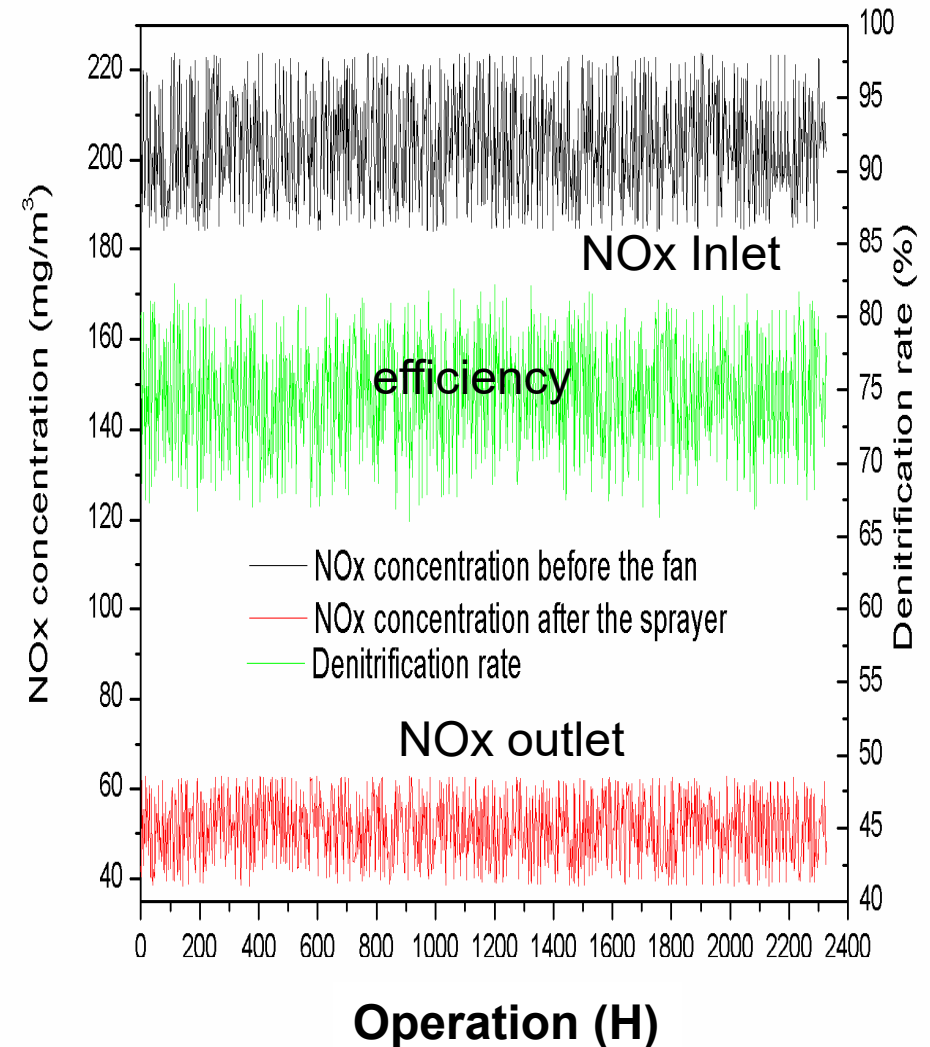
Indirect NTP Gas Cleaning

35 t/h & 85,000m³/h

Before FGD

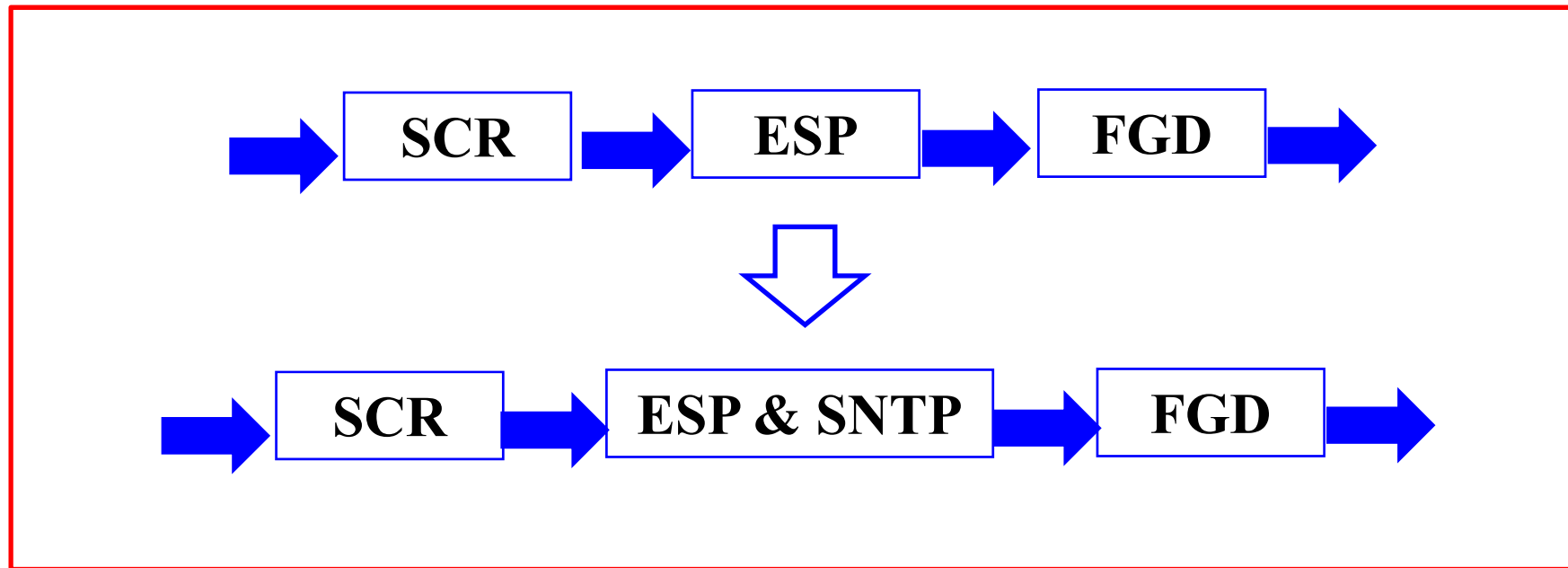


After FGD



SCR-ESP & SNTP-FGD

Demonstration with 660MW



ESP to NTP Upgrading:

660MW

PM $\leq 15 \text{ mg/m}^3$

1, 2
FIELDS

3
FIELD

4
FIELD

5
NTP

PM

$\leq 120 \text{ mg/m}^3$

$\leq 50 \text{ mg/m}^3$

$\leq 20 \text{ mg/m}^3$

$\leq 15 \text{ mg/m}^3$



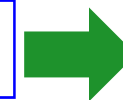
NOx

$\Delta \geq 20 \text{ mg/m}^3$

$\Delta \geq 40 \text{ mg/m}^3$

$\Delta \geq 60 \text{ mg/m}^3$

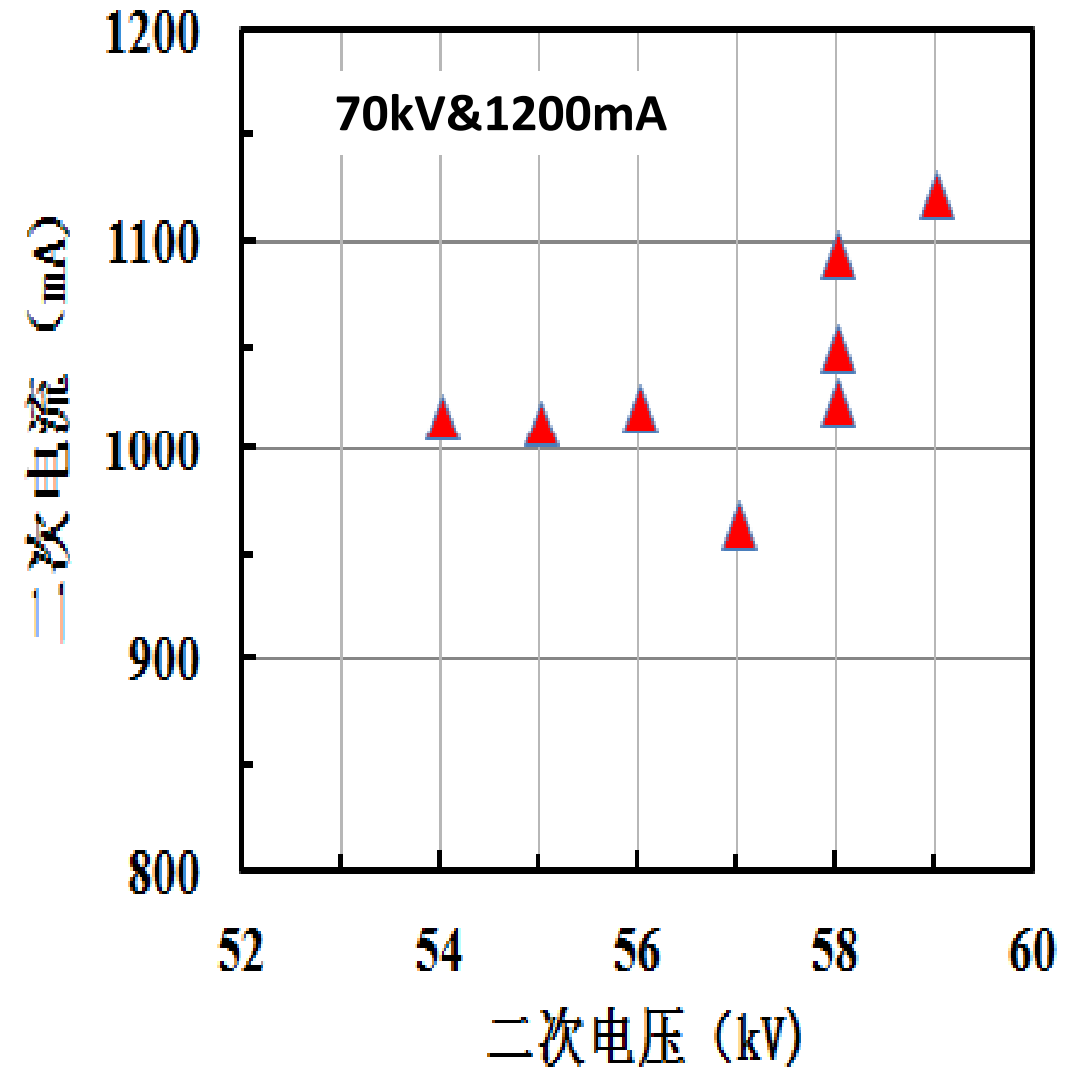
SCR: $40\text{-}80 \text{ mg/m}^3$



$< 20 \text{ mg/m}^3$

SCR-ESP & SNTP-FGD

8 SNTP POWER SOURCES

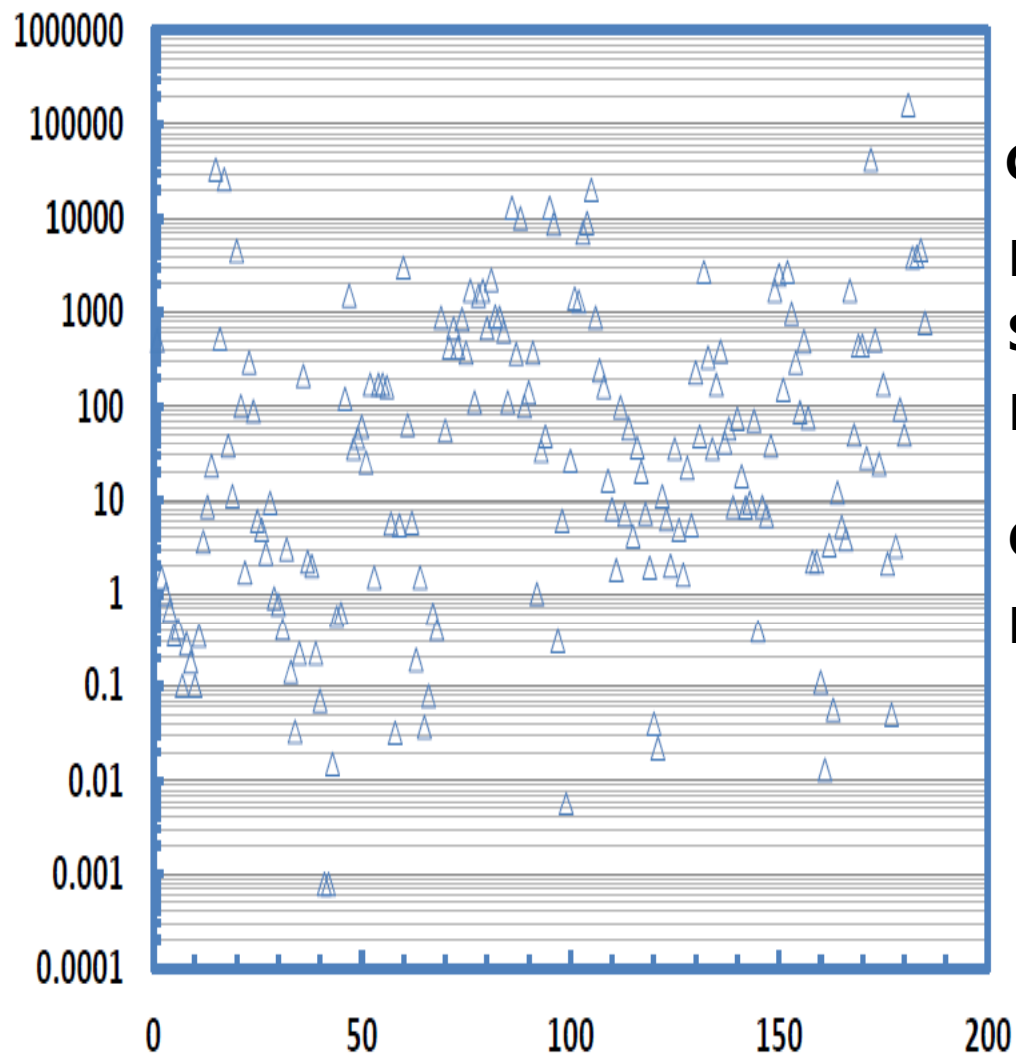


SNCR+ESP+DNTP+FGD

75t/h



Odor Thresholds (ppb)



CH₃OH 33ppm

NH₃ 1.5ppm

SO₂ 870

NO₂ 120

O₃ 3.2

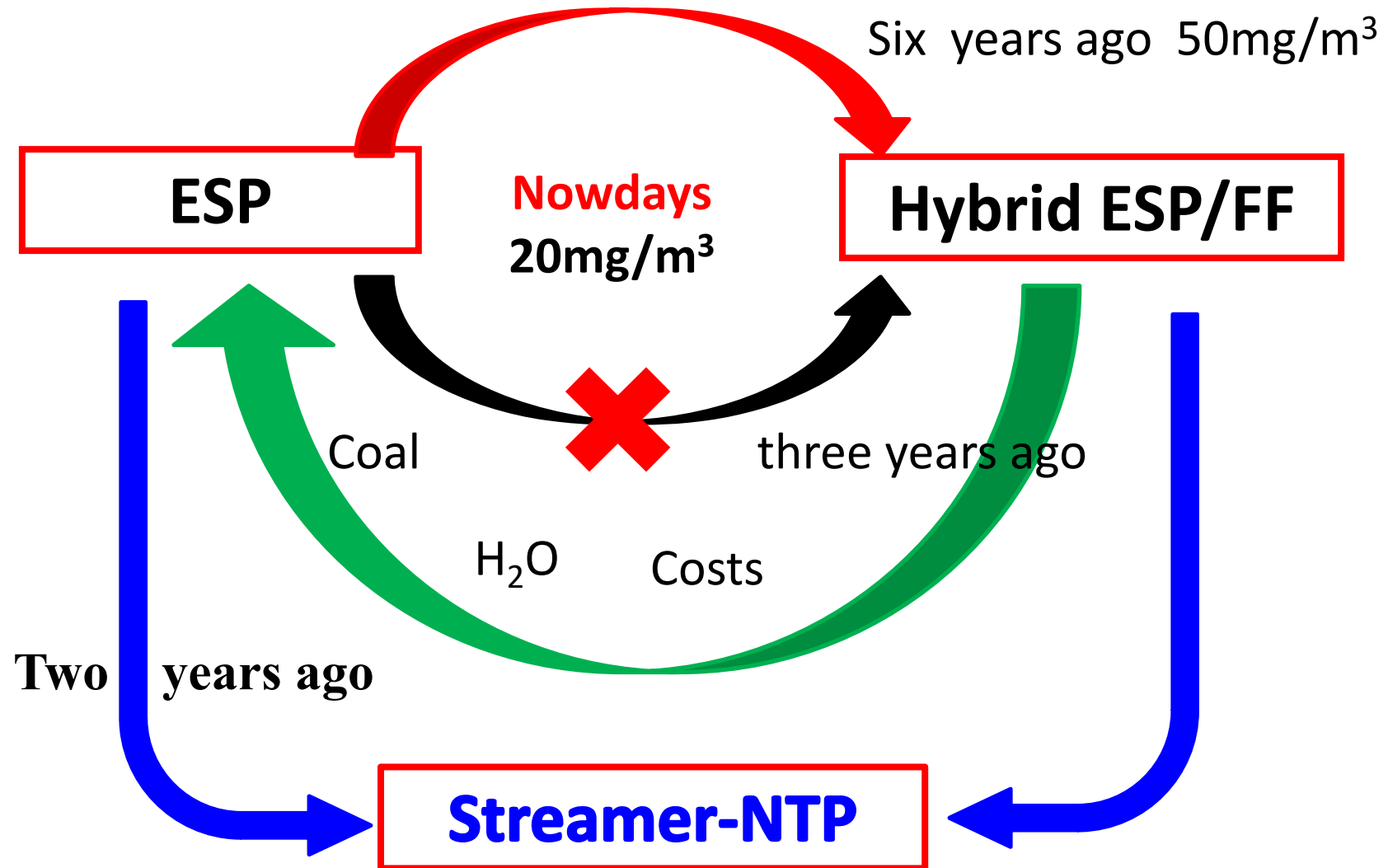
H₂S 0.4

"S" related

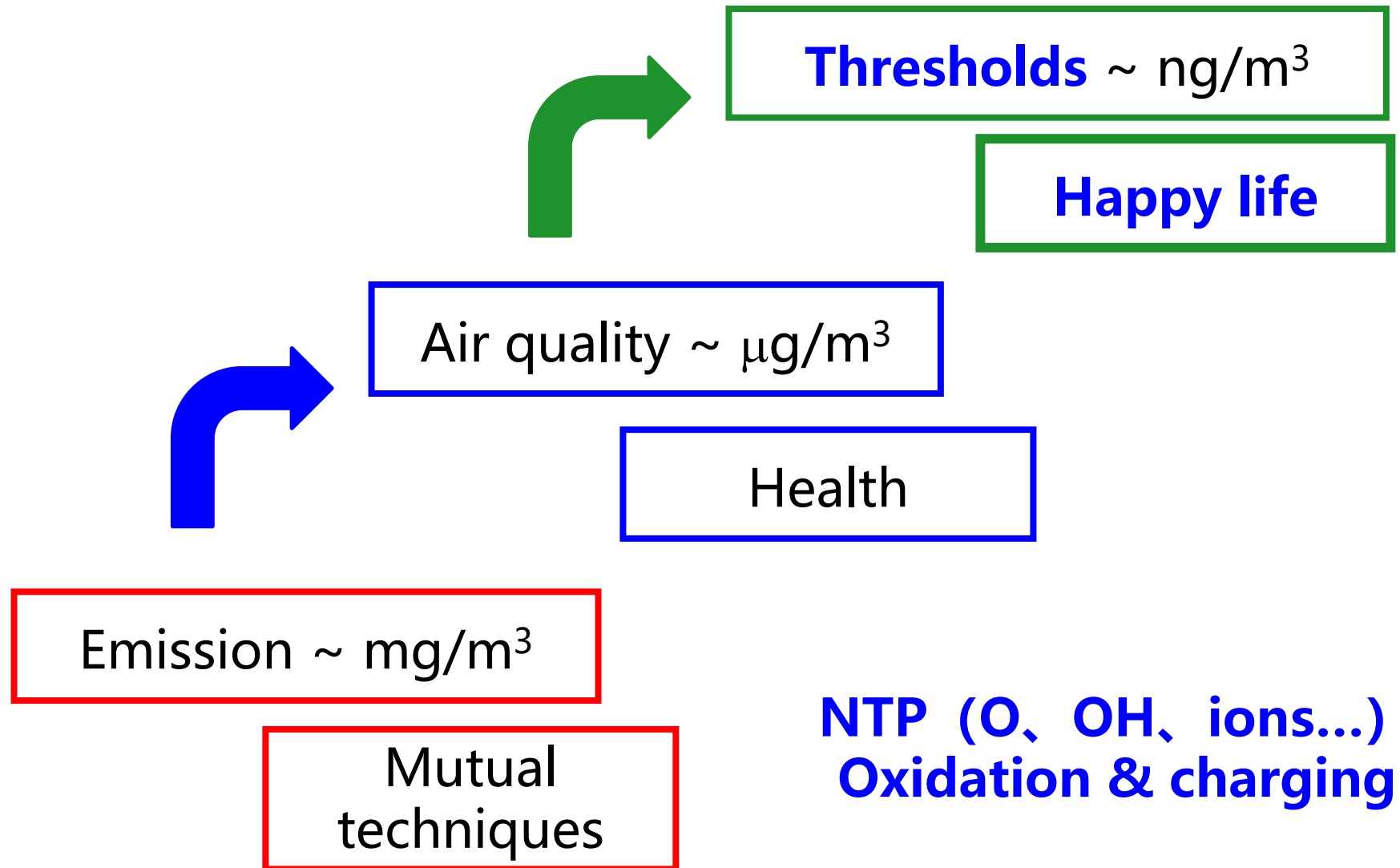
2x100kVA DNTF
250000m³/h
NH₃, H₂S, CS₂



ESP&FF&NTP: past, today and **future**



Future Prospects



Future Prospects

- 1. Non-Thermal Plasma Systems will become as popular as ESP for Multi-pollutants Emission Control**
- 2. Plasma Sonar has been widely Applied for Marine Services**
- 3. Nano-second Pulsed Electrical Field is very efficient for cancer treatment**