Control of Industrial Air Pollution in Japan

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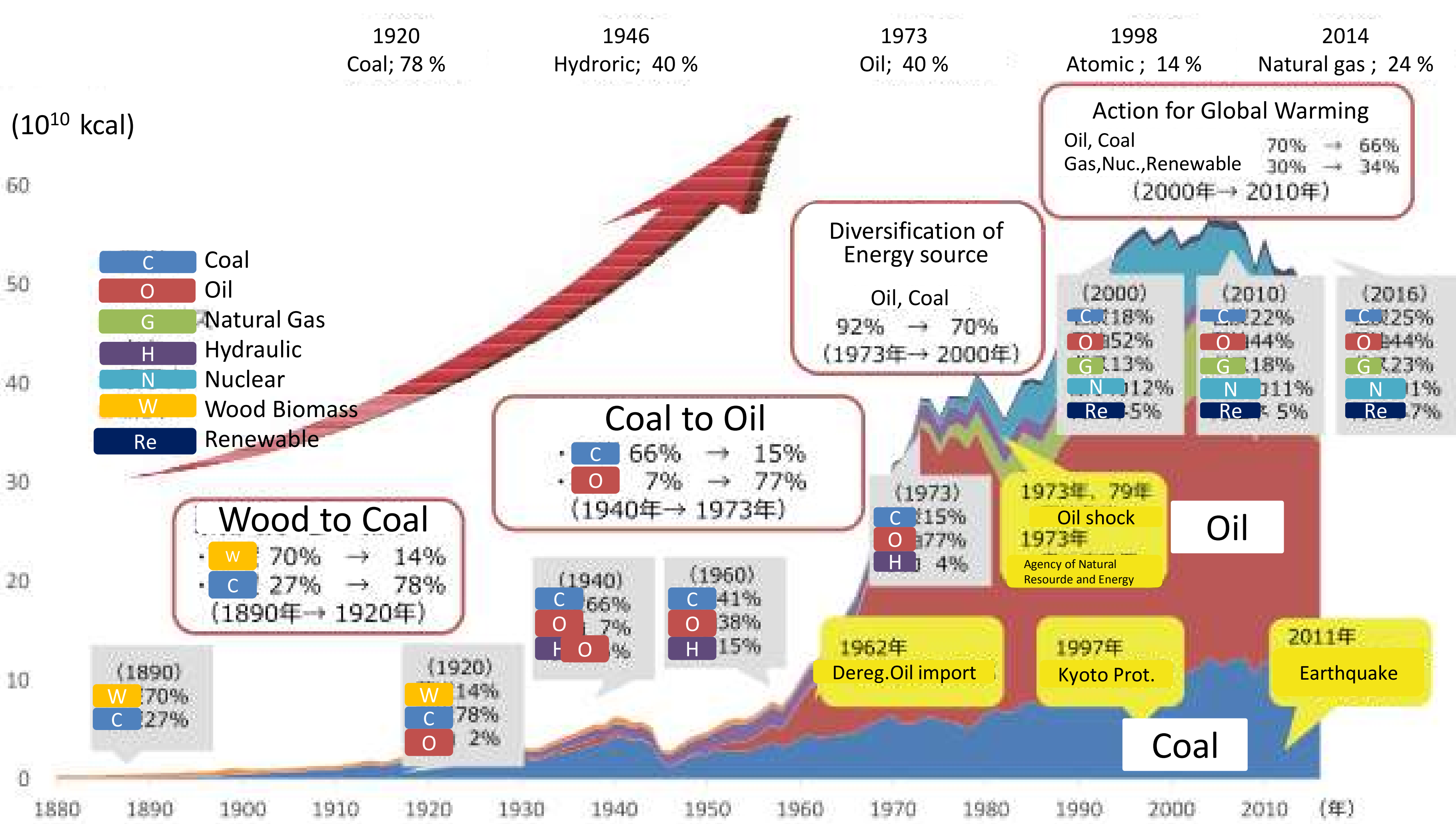
Change of the primary energy source in Japan



出典：日本エネルギー経済研究所資料より資源エネルギー庁作成

1960’s
Seto-city

Famous for ceramic products

Several major pollutions in Japan

1880s Ashio copper mine poisoning

1910s Itai-itai Disease

1956 Minamata Disease

1960s Yokkaichi Asthma

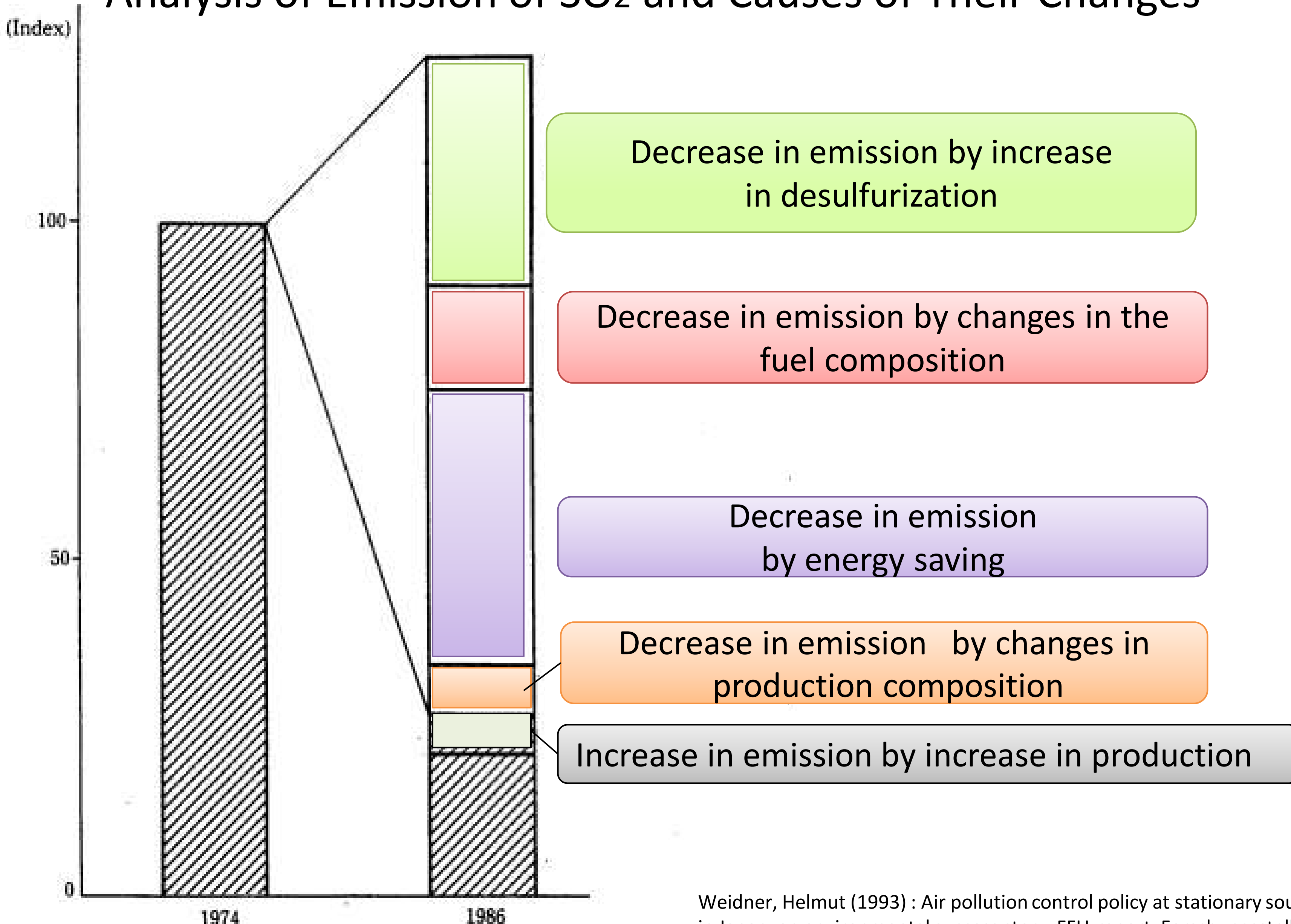
After Meiji restoration, modern industrialization started. Then, pollution became serious problem. With growing in pollution opposition movements nationally, the government in 1967 enacted the Basic Law for Environmental Pollution Control.

The Law on Special Measures Concerning Redress for Pollution-Related Health Damage, enacted in 1969, designated part of Yokkaichi, Osaka, Kawasaki, and other places as polluted areas.

In 1972 the so-called Absolute Liability Law was enacted.

In 1990s, there was increasingly heavy air pollution from vehicles, especially diesels.

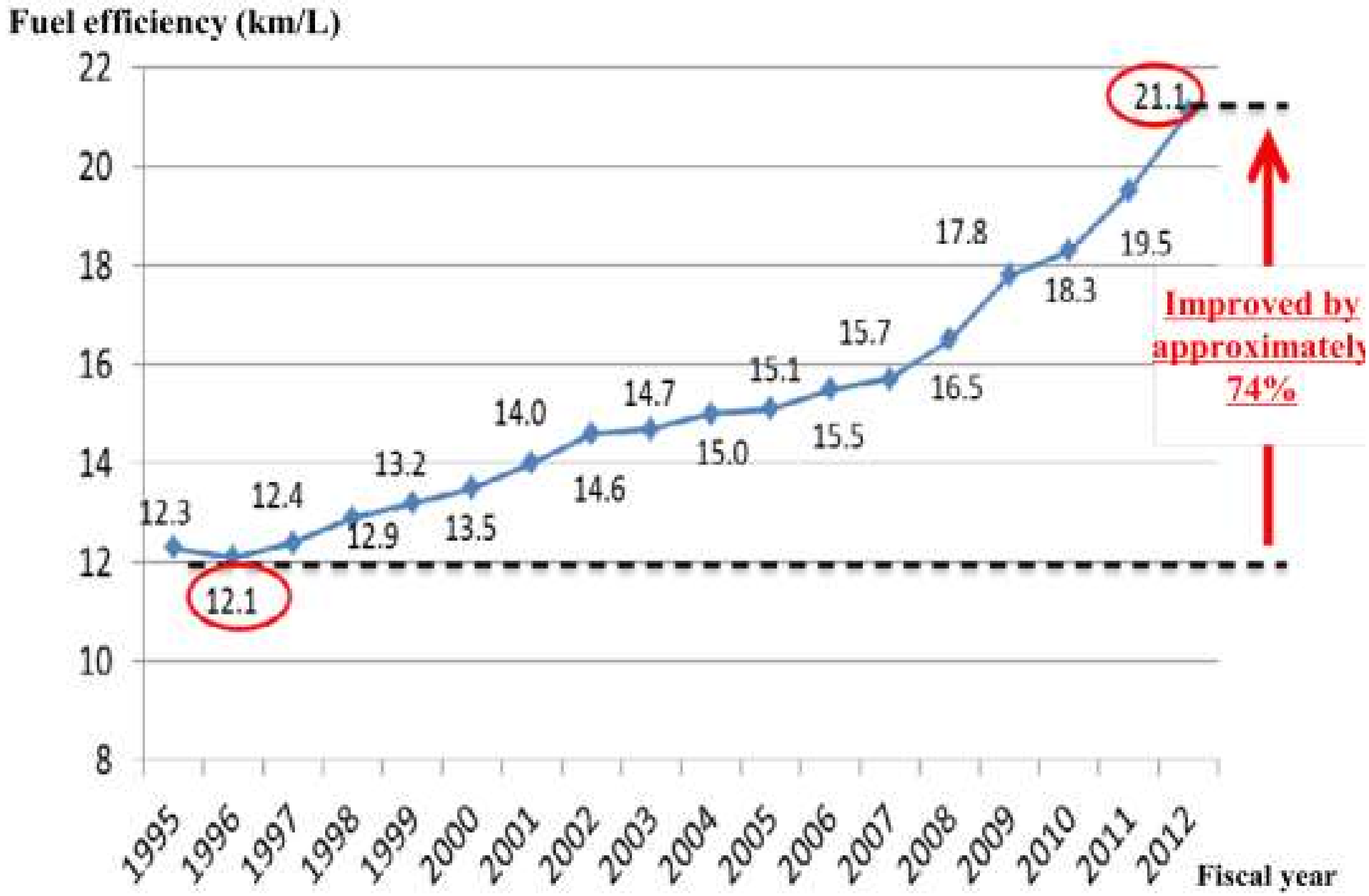
Analysis of Emission of SO_2 and Causes of Their Changes



For the index, the emission o f 1974 is set at 100.
Source: Environment Agency 1992: 75

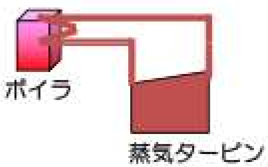
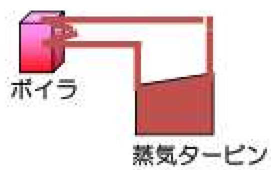
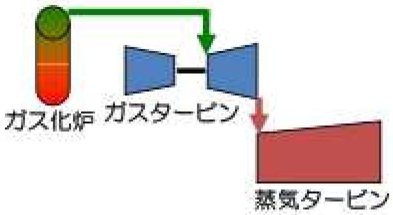
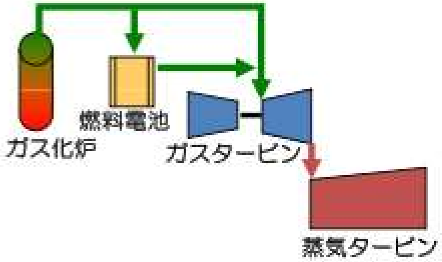
Weidner, Helmut (1993) : Air pollution control policy at stationary sources in Japan: an environmental success story, FFU-report, Forschungsstelle für Umweltpolitik, Freie Universität Berlin, No. 93-6, Forschungsstelle für Umweltpolitik, Freie Universität Berlin, Berlin

Example of Improvement in Gasoline-Fueled Passenger Cars -Changes in Average Fuel Efficiency-

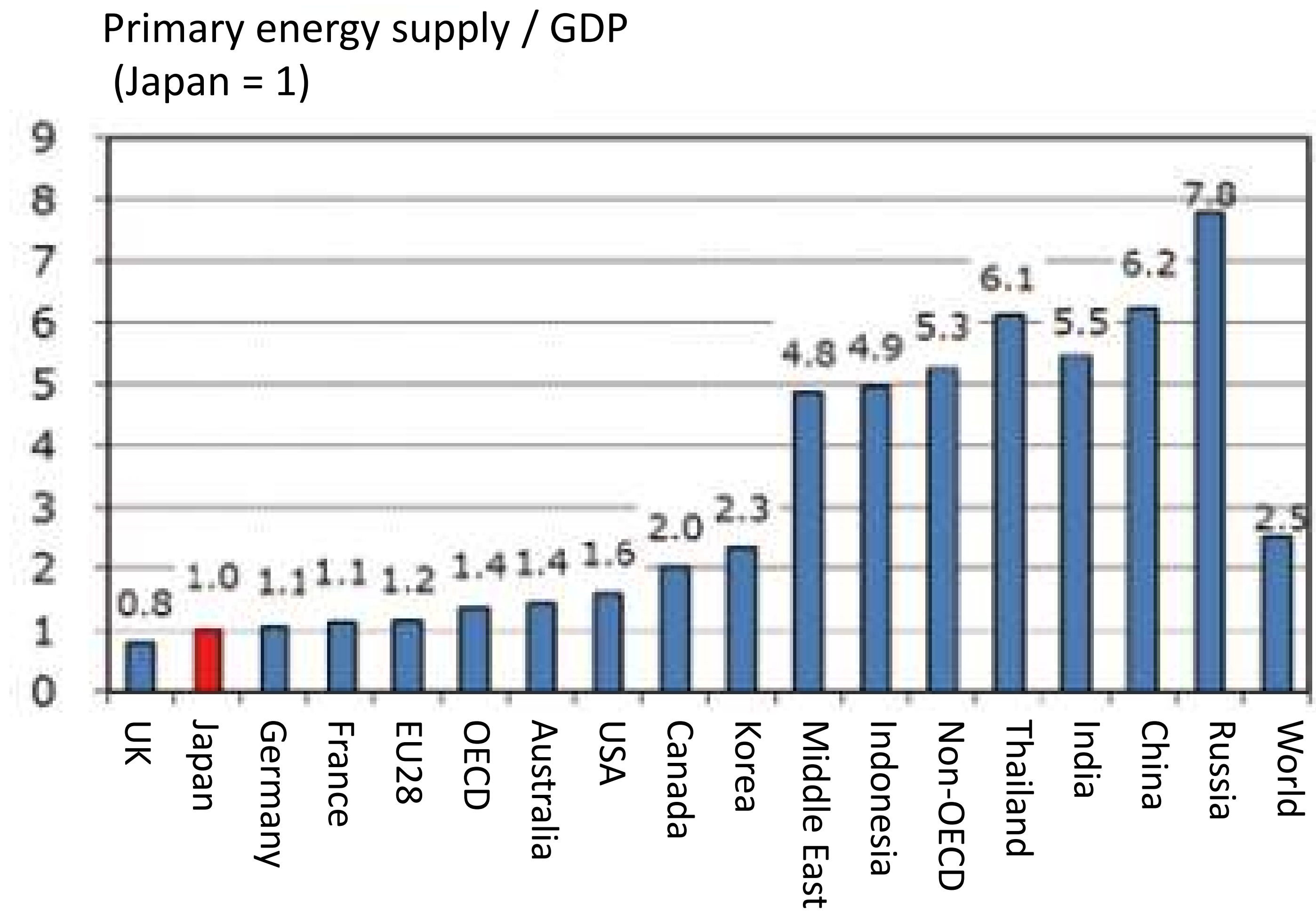


○ Changes in the average 10-15 mode fuel efficiency of gasoline fueled passenger cars
[Source] Created based on the data from the Ministry of Land, Infrastructure, Transport and Tourism

Technology to increase efficiency of power generation by coal

PCF:Pulverized Coal fired		IGCC:Integrated Gasification Combined Cycle (~1,500 C)	IGFC:Integrated Gasification Fuel Cell Combined Cycle
USC:Ultra Super Critical 	A-USC:Advanced Ultra Super Critical (750 C) 	Gas & Steam turbine 	Fuel cell + Gas&Steam turbine 
Sending end efficiency 41 %	48 %	48 % CO_2 reduction 15 %	Over 55 % CO_2 reduction 30 %

Consumption of primary energy per GDP



Japanese Energy White Paper 2018

2,018　エネルギー白書
（注）一次エネルギー消費量（石油換算トン）÷実質GDP（米ドル、2010年基準）を日本＝1として換算
出典：IEA「World Energy Balances 2017 Edition」、World Bank「World Development Indicators 2017」を基に作成

Annual average concentrations of Pollutants in Japan

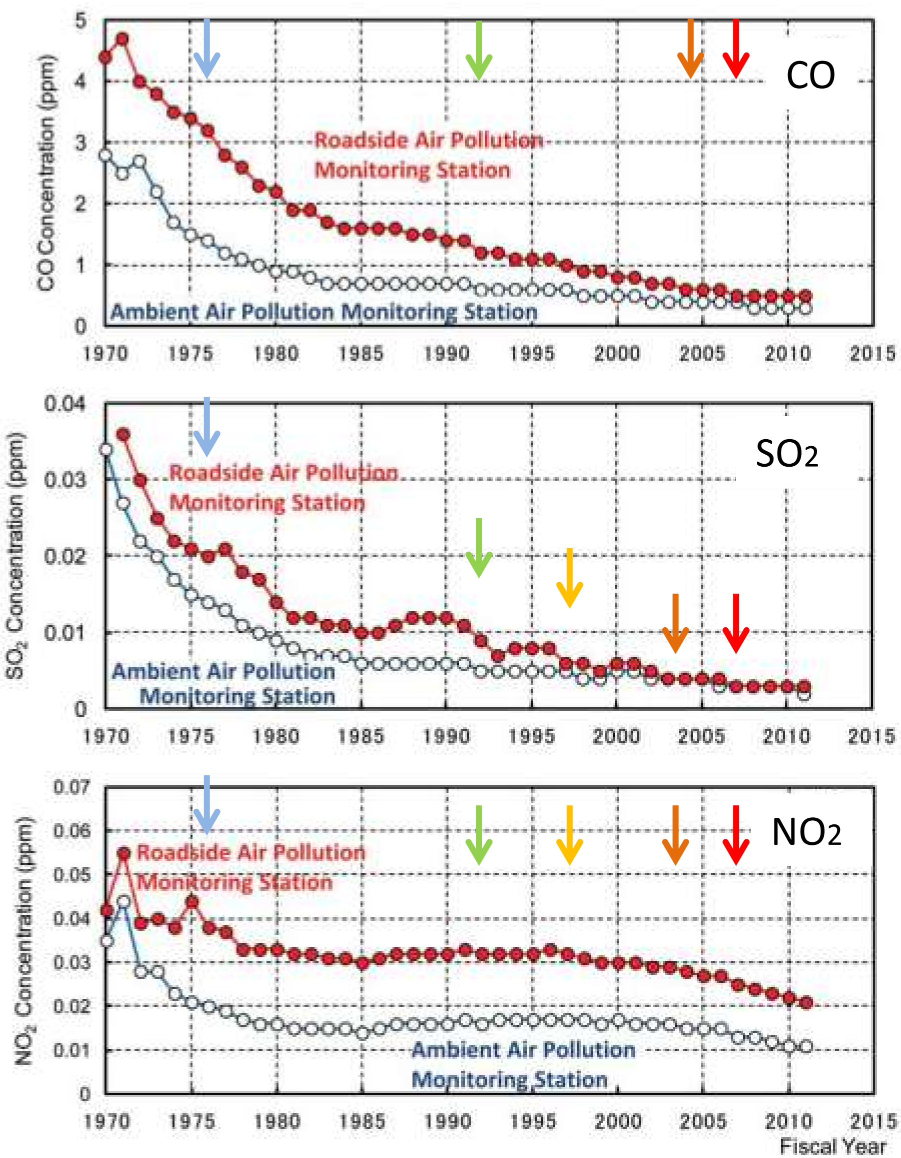
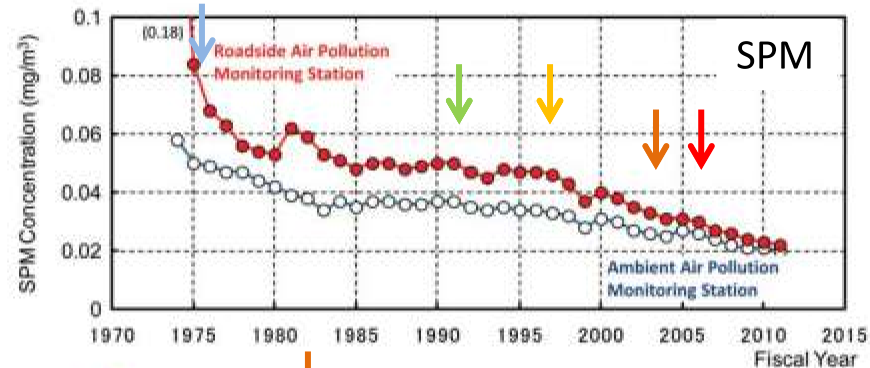
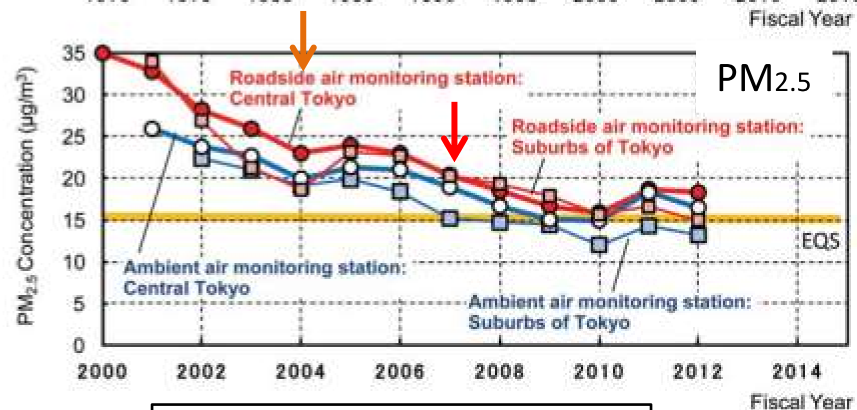


Fig. 2. Annual average concentrations of CO, SO_2, and NO_2 (1970-2012).





Sulfer in diesel fuel

1953	1.2	%
1976	0.5	%
1992	0.2	%
1997	0.05	%
2004	0.005	%
2007	0.001	%

Shinji Wakamatsu, Tazuko Morikawa and Akiyoshi Ito, "Air Pollution Trends in Japan between 1970 and 2012 and Impact of Urban Air Pollution Countermeasures"Asian Journal of Atmospheric Environment Vol. 7-4, pp.177-190, December 2013 doi:http://dx.doi.org/10.5572/ajae.2013.7.4.177

Regulation of pollution in Japan

- Basic Law for Environmental Pollution Control (1967)
- Air Pollution Control Law (1968)
- Water Pollution Control Law (1970)

  (Establishment of Environment Agency (1971))

- Law Concerning Special Measures for the Conservation of Lake Water Quality(1984)
- Automobile NOx Law (1992)
- Environment Basic Law (1993)

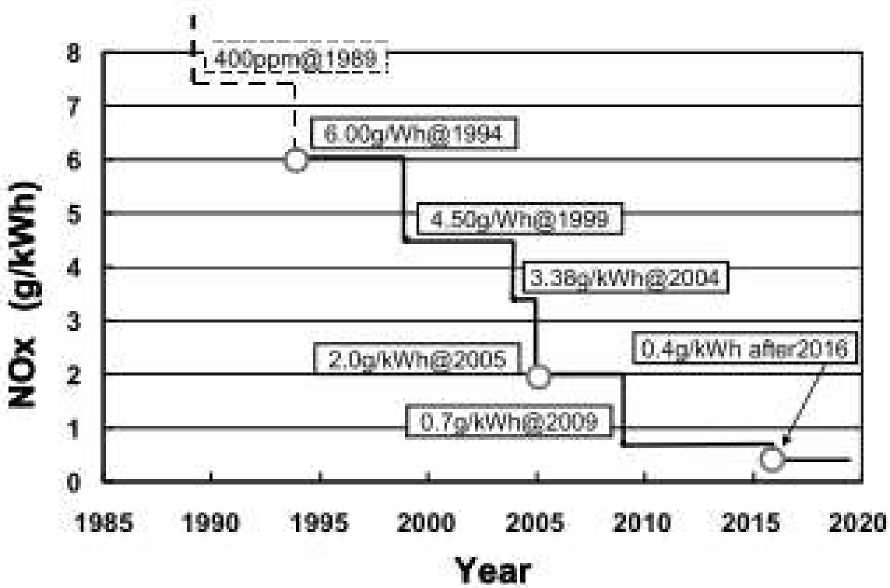
  (Inauguration of the Ministry of the Environment (2001))

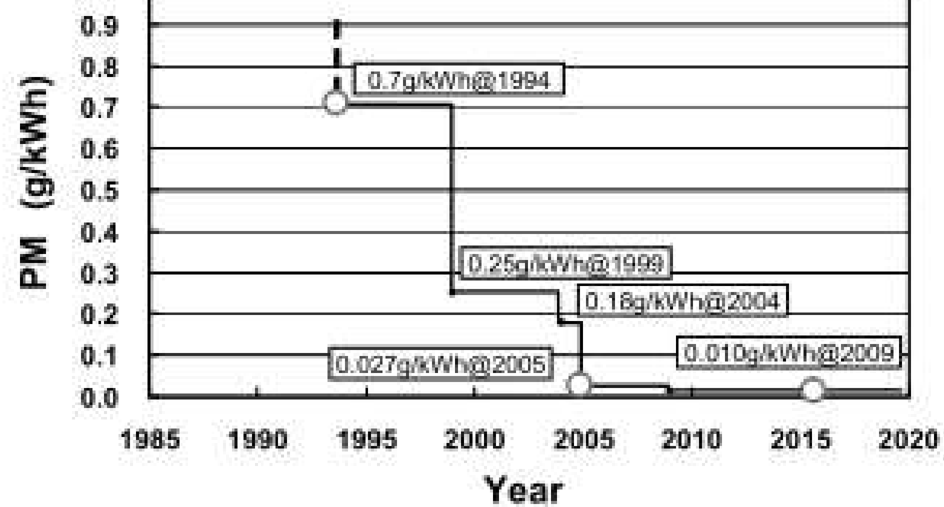
- Automobile NOx PM Control Law (2001)
- Amendment of Air Pollution Control Law and Water Pollution Control Law (2010)

Regulation of heavy vehicle (more than 12 ton) exhaust in Japan

Fuel	Gas component	Limit value (g/kWh)
Gasoline & LPG	CO	21.3 (16.0)
	NMHC	0.31 (0.23)
	NOx	0.9 (0.7)
	PM (*2)	0.013 (0.010)
Diesel	CO	2.95 (2.22)
	NMHC	0.23 (0.17)
	NOx	0.9 (0.7)
	PM	0.013 (0.010)

( ) averaged limit value for the same model





Environmental Standards and regulations

Environmental Standards	
CO	The daily average for hourly values shall not exceed 10 ppm (12 mg/m^3), and average of hourly values for any consecutive eight hour period shall not exceed 20 ppm (23 mg/m^3).
SO_2	The daily average for hourly values shall not exceed 0.04 ppm (105 µg/m^3), and hourly values shall not exceed 0.1 ppm (262 µg/m^3).
NO_2	The daily average for hourly values shall be within the 0.04-0.06 ppm (75-113 µg/m^3) zone or below that zone.
OX	Hourly value should not exceed 0.06 ppm (118 µg/m^3).
SPM	The daily average for hourly values shall not exceed 0.10 mg/m^3, and hourly values shall not exceed 0.20 mg/m^3.
$PM_{2.5}$	The annual standard for $PM_{2.5}$ is less than or equal to 15.0 µg/m^3. The 24 hour standard is less than or equal to 35 µg/m^3.
Environmental Guideline	
NMHC	Hydrocarbon levels should be determined by measuring the non-methane hydrocarbons. The 3 hour (6-9 a.m.) average concentration should be 0.20-0.31 ppmC or less (equivalent to the value in terms of ppm obtained by adding up the figures gained through the carbon molecules multiplied by the number of carbon atoms per molecule).

The total number of ambient air pollution monitoring stations in Japan in 2011 was 1509.
The total number of road-side air pollution monitoring stations in Japan in 2011 was 425.
(Roadside air pollution monitoring stations regularly monitor the ambient air at or near intersections, roads, and roadsides deemed to be polluted.)

Pollution Control Manager System

The main function of Pollution Control Managers is to supervise workers at the facilities to meet environmental standards for exhaust gas and waste water.

A factory of a certain scale must have the Pollution Control Manager that holds the certificate of National qualification test.
(Smoke emission: 40,000 m3/h or more Effluent: average 10,000 m3/day or more)

- Supervisor for Pollution Control (Factory Manager)
  - Chief Manager for Pollution Control (Exhaust Gas & Waste Water) (Environment Control Department Manager)
    - Pollution Control Manager (exhaust gas)（Environment Control Division Chief)
    - Pollution Control Manager (waste water)（Environment Control Division Chief)
  - Pollution Control Manager (noise/vibration/dust & dioxins)（Environment Control Division Chief)

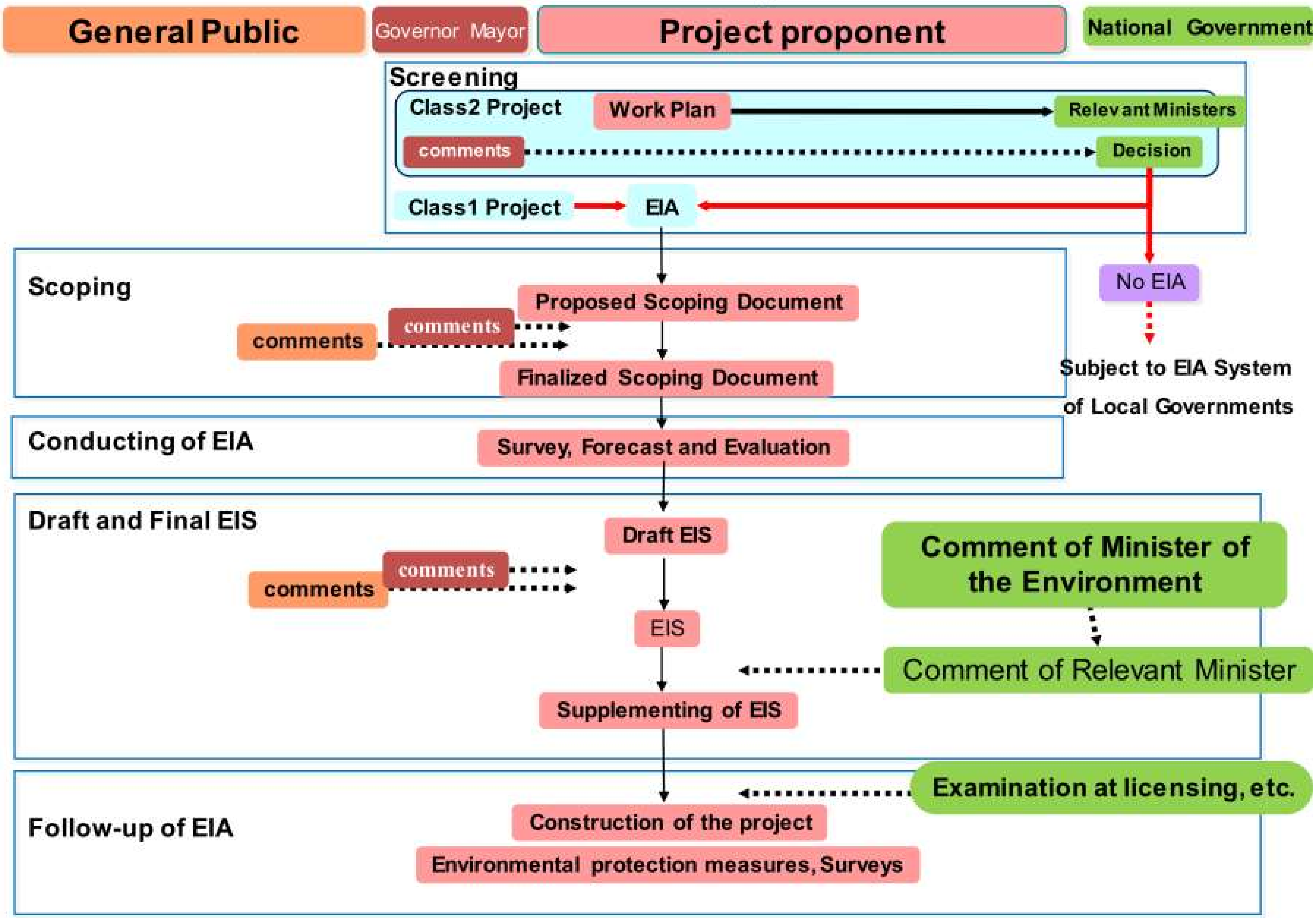
Efforts by the Private Sector

Agreement on environmental pollution control between private sector and local governments/citizens groups

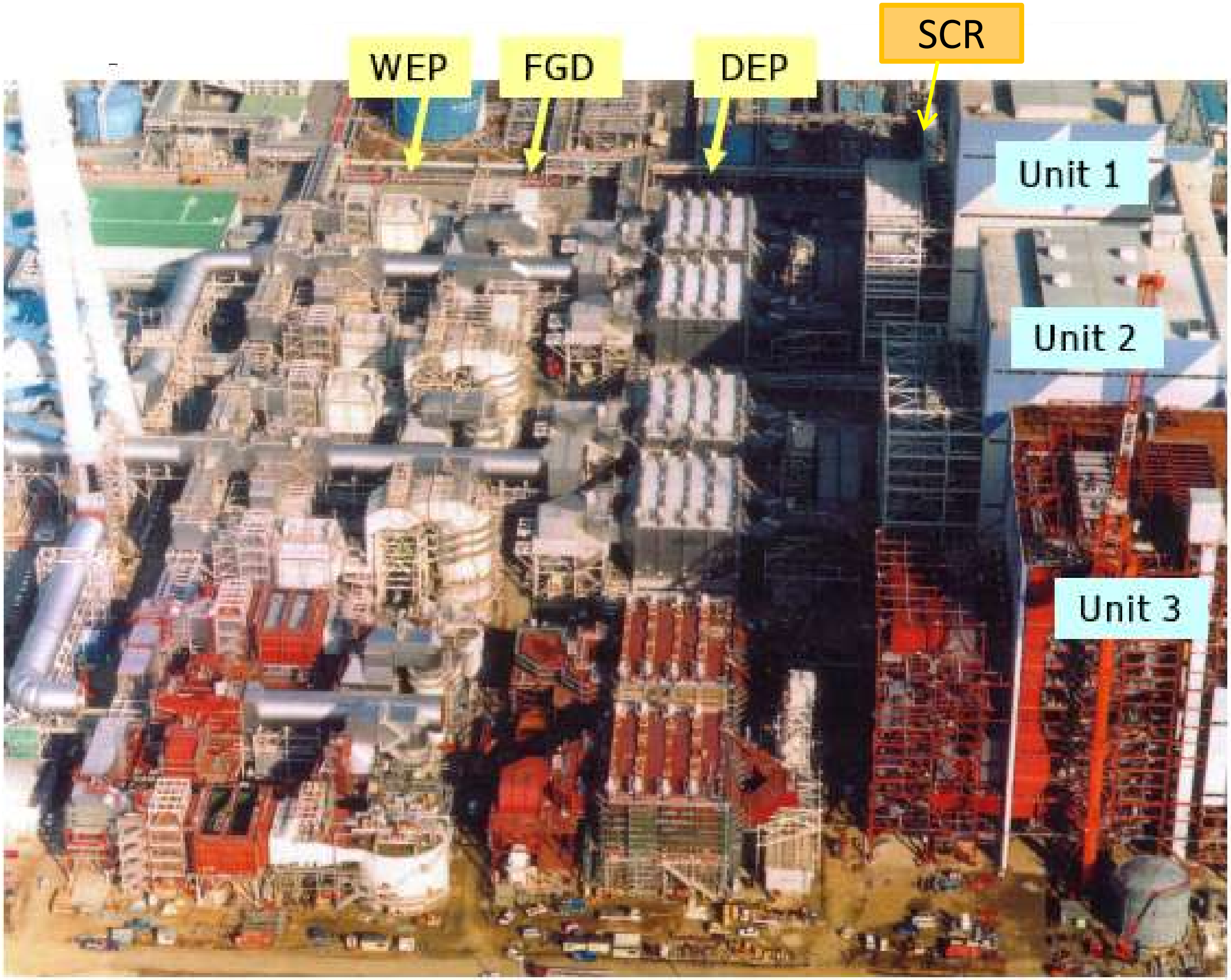
Functions of the Agreement

1) Supplementary pollution control measure, often more stringent.
2) Implementation of pollution control with close attention to local conditions
3) Promotion of future pollution control measures and development of pollution prevention technologies
4) Prevention of protests against location of factories by getting agreement from local residents

Procedures of Environment Impact Assessment Law



Flue gas cleaning system for coal fired electric power generation



Chubu Electric Power Co.

Hekinan Power Station

Unit 1, 2, 3

700MW x 3 units

Coal Fired Boiler

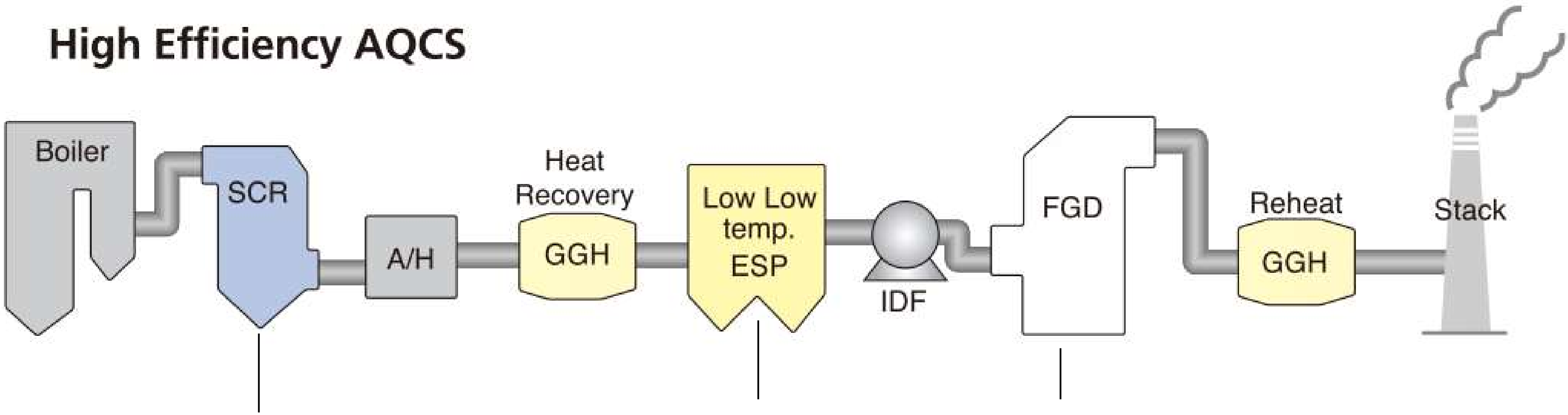
Operation Started

in 1991, 1992, 1993

Gas Volume / unit

2,540,000 m^3N/h-wet

An Example of modern flue gas cleaning system



NO removal
Catalytic reduction

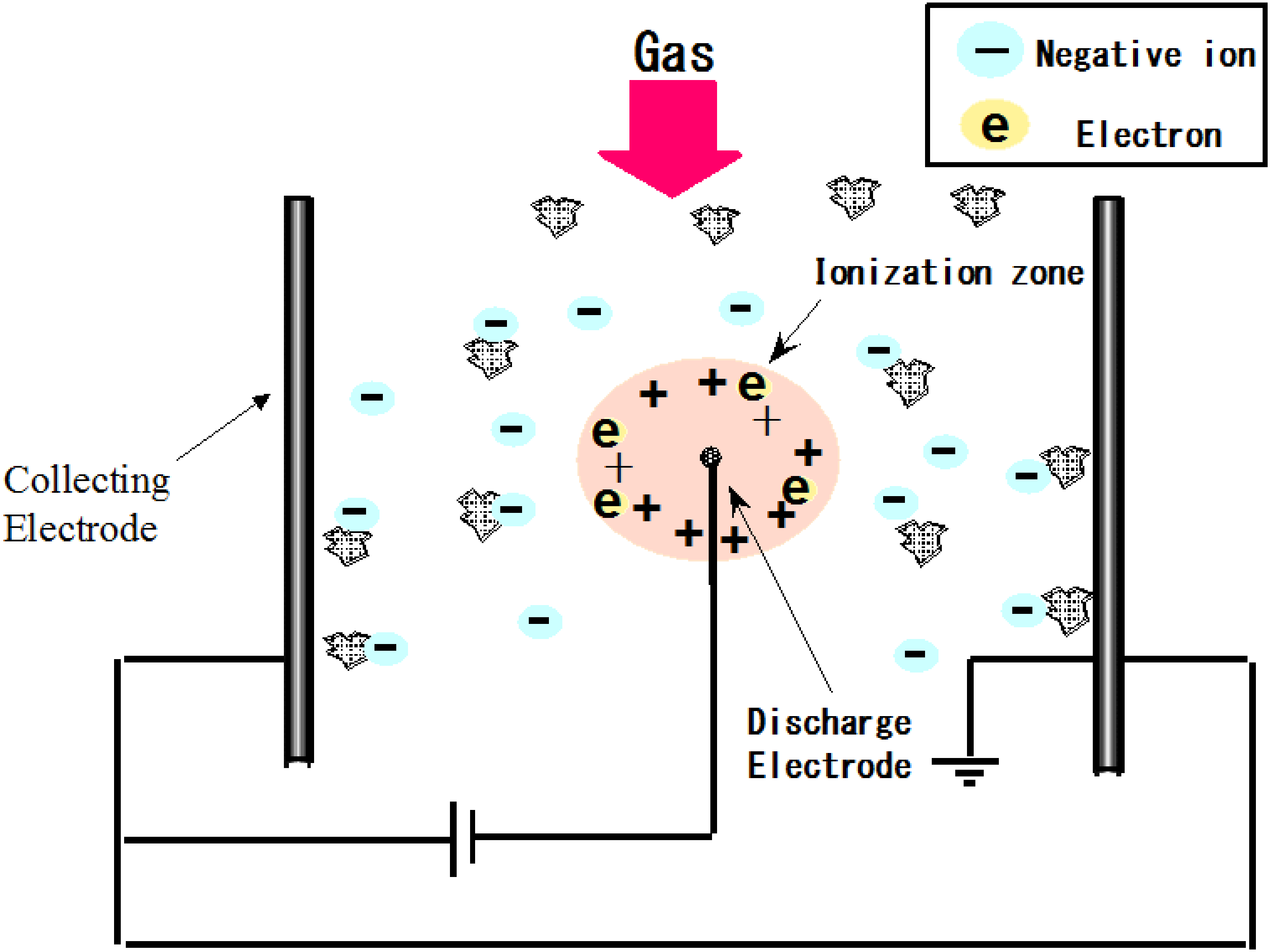
Dust removal

Electrostatic
Precipitation
Low pressure drop

SO_2 removal
Wet-scrubbing

Catalog: Mitsubishi Hitachi Power Systems

Electrostatic Precipitation for dust removal



COTTRELL
ELECTRICAL PRECIPITATION PROCESSES
IN JAPAN

By Dr. Ritaro Hirota and Kyoshi Shiga.

The history of the Cottrell Electrical Precipitation Processes in Japan begins with the purchasing of the Cottrell patent rights in 1916 by Mr. T. Wada, representing seven principal mine owners in Japan, from the International Precipitation Company of Los Angeles, California, U. S. A., of which Mr. Walter A. Schmidt is president. Prior to this, the negotiations were opened between Mr. Wada and the International Precipitation Company, through Mr. H. W. Paul, the Precipitation Company's agent for Japan.

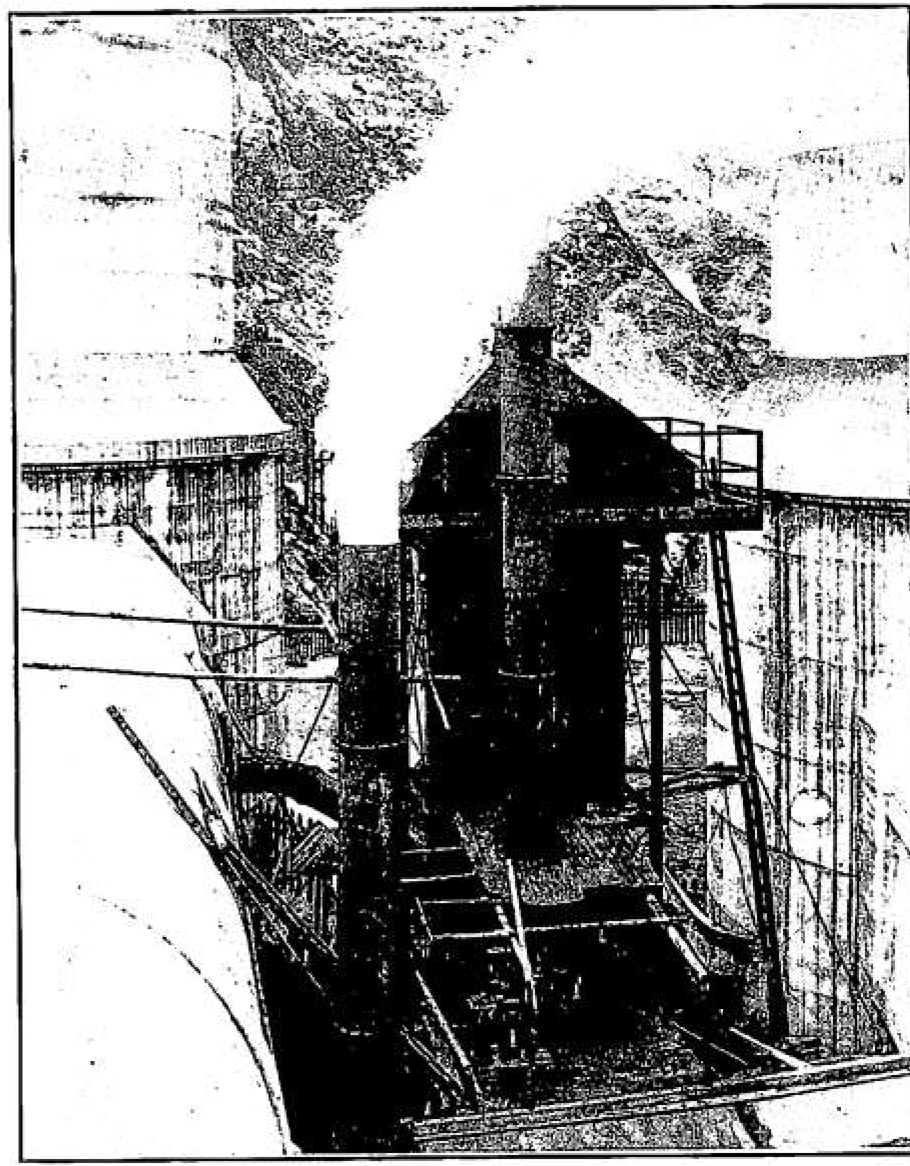


Figure 1.
Experimental Treater at Ashio, Electrical Current Off.

Ritaro Hirota and Kiyoshi Shiga, "Cottrell Electrical Precipitation Processes in Japan", Kinzoku-kogyo kenkyusho (Metallurgical Research Institute) No.1, Yaesu-cho 1 chome, Kojimachi-ku, Tokyo, Japan, September, 1919

Motoji Shibusawa, Yasujiro Niwa,
“On the Precipitation Treater with Glass-covered Electrodes”
Journal of the Institute of Electrical Engineers Japan, 1924

演　說　豫　稿

電極を絶縁物にて覆ひたる電氣沈澱裝置に就て

(On the Precipitation Treater with Glass-covered Electrodes)

(大正十年四月東京支部演說豫稿)

會員　工學博士　澁　澤　元　治
會員　工學士　丹　羽　保　次　郎

内　容　梗　概

電極を絶縁物にて被ひたる電氣沈澱方式を日光電氣精銅所に於ける電氣沈澱設備に應用したる實驗結果を詳細に述べ電極の構造、電極間の放電、コロナ状態、所要電力等に於て從來の方式に比し幾分優れる事を示し此の方式の應用範圍を述べたり。次に本方式の理論につき考究し沈澱管內の電位傾度の狀態を靜電的に論じ次に實驗によりて求めたる値と比較したり。最後に比較的大なる電流が絶縁物を通じて流るゝ現象につき考究し其の原因を絶縁體が温度及び電位傾度によりて其の抵抗を減少すること及び絶縁體の表面に自由電荷を生じて絶縁體中の電位傾度が靜電的に計算したるものより大なることに歸したり。

電極を絶縁物にて覆ひたる電氣沈澱裝置に就て

綜合報告

電氣收塵法と其應用

會員 福田節雄
（東京帝國大學電氣工學科）

Electrical Precipitation and Its Application.

By Setsuo FUKUDA, Member
(Tokyo Imperial University)

內容要概

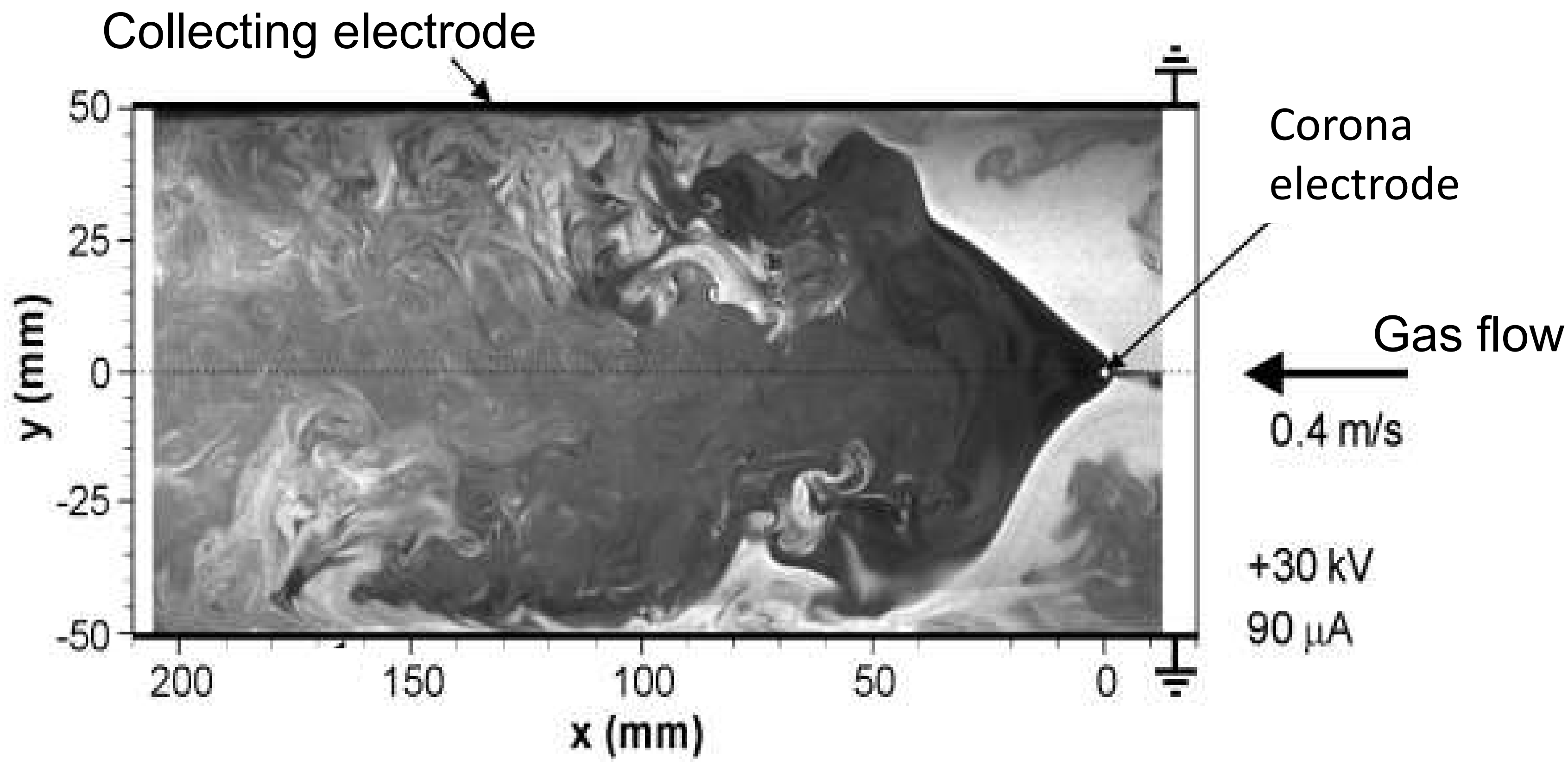
本文は、電氣收塵法に於ける基礎的現象と、其現在までに於ける應用の狀況とを、主として本問題に就て之までに發表された文獻に從つて、說明的に記述したものである。

目次

Setsuo Fukuda, "Electrostatic precipitation and its application"
Journal of the Institute of Electrical Engineers Japan, 1930

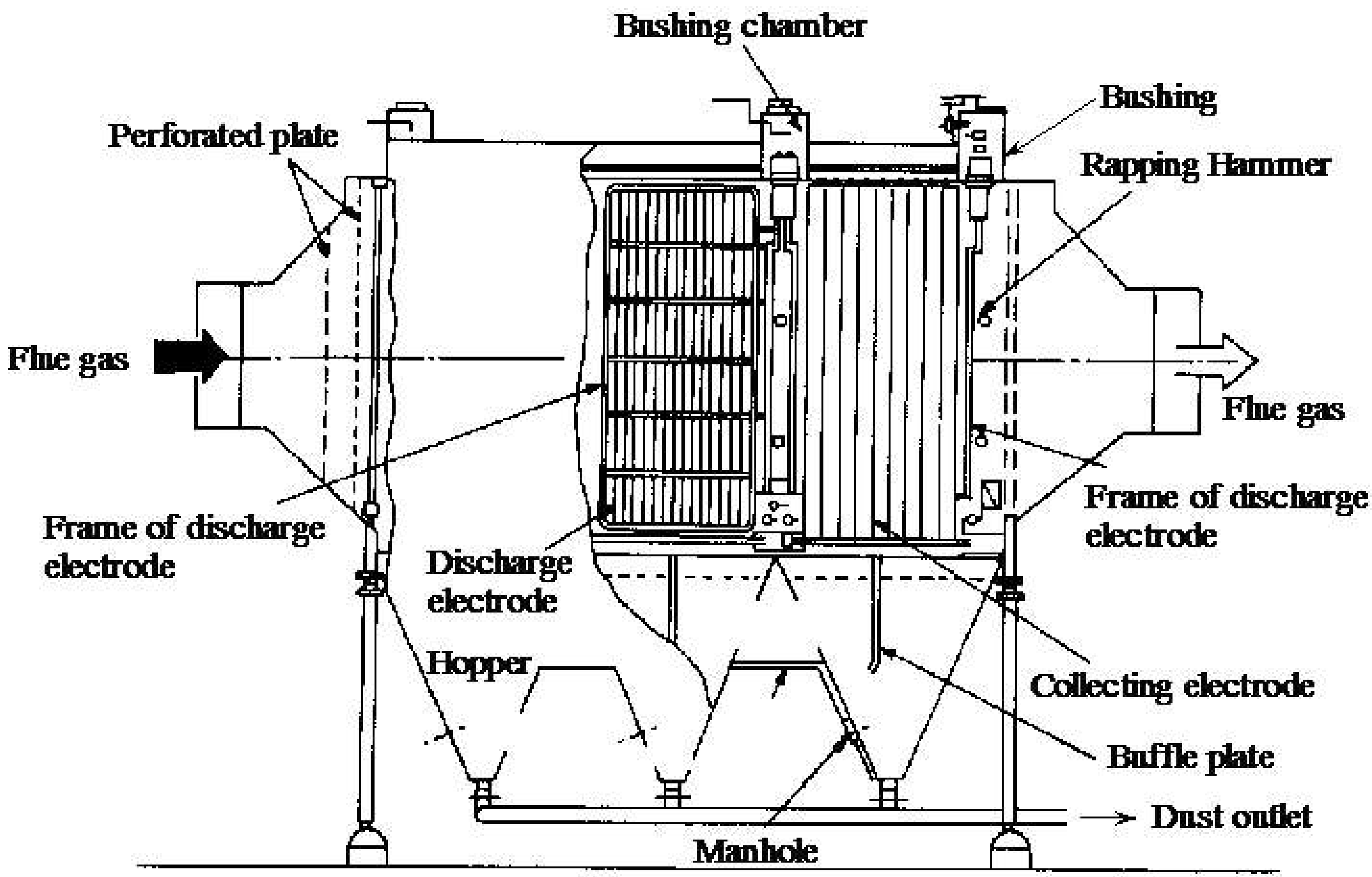
Movement of particles inside an ESP

Inside an ESP, particles are charged by the corona discharge, and driven towards the collecting electrode. Ionic wind is generated, associated with the movement of ions from the corona tip to the grounded collection electrode, and synergetic effect is obtained to drive suspended particles. However, after the ionic wind reach to the collecting electrode, the wind becomes more turbulent and carry the suspended dust away to the spacing. This advisory effect is significant in ESPs.



J. Mizeraczyk *et. al.*, *Journal of Electrostatics,* Vol. 66, pp. 246-253, 2008

Typical construction of plate type electrostatic precipitator

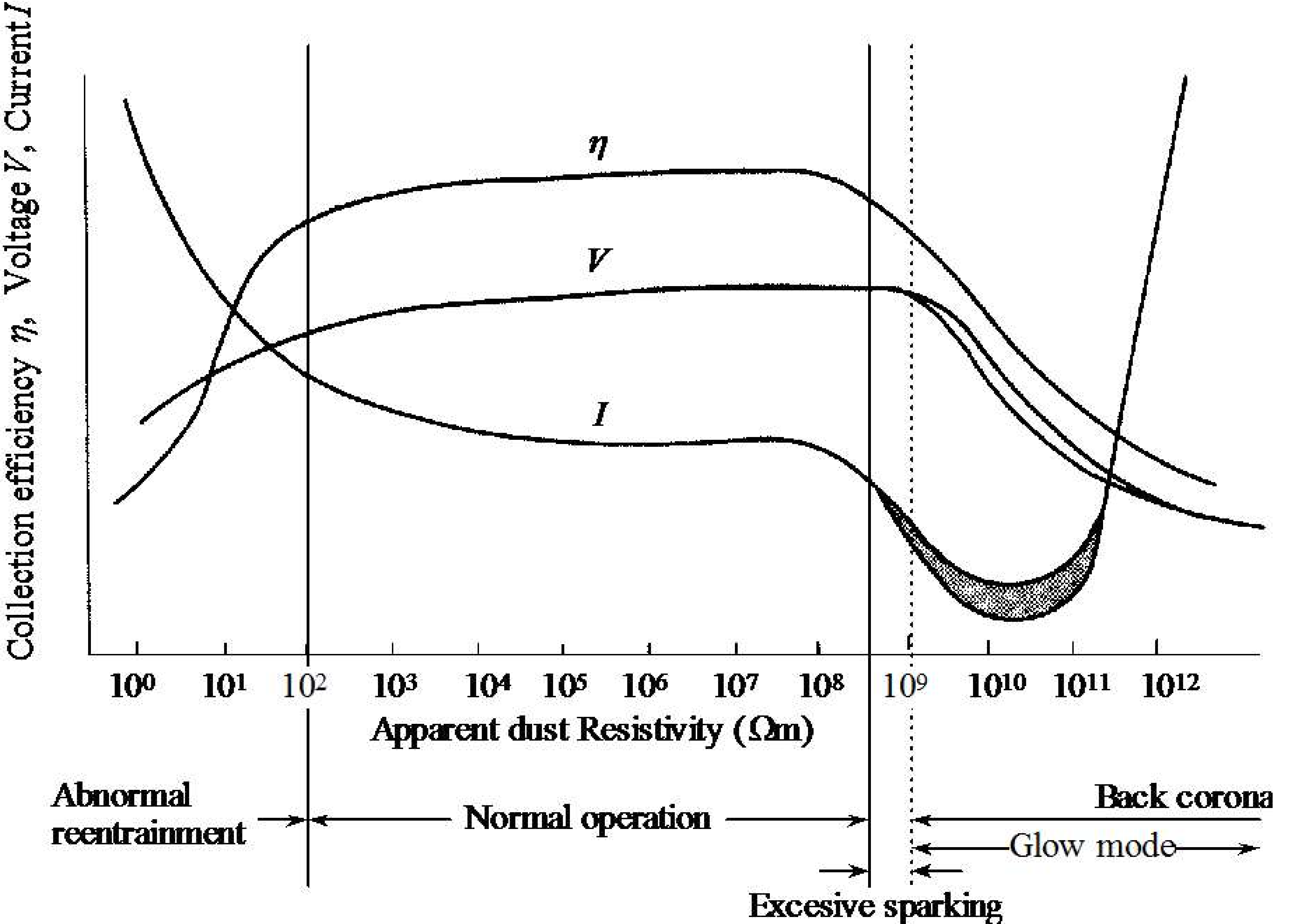


This figure shows a plate type ESP consisting of parallel plate electrodes for dust collection. The discharge electrodes are located between the plates. The gas flow is horizontal. This is a dry, one stage ESP. This type is used commonly in many industrial applications

FEATURE OF ESP

1. Fine particles can be collected effectively over a wide range of temperature
2. The power consumption is low because the pressure drop is small (1 to 2 kPa) and the current density is low (0.3 mA/m^2).
3. Maintenance is easy as the number of moving parts is small.
4. The collection efficiency is affected by the dust resistivity ρd . When $\rho d<10^2$ ohm-m, abnormal dust re-entrainment takes place. When $\rho d > 5x10^8$ ohm-m, back corona takes place. For these extremely low or high resistivity dusts, the collection performance decreases.

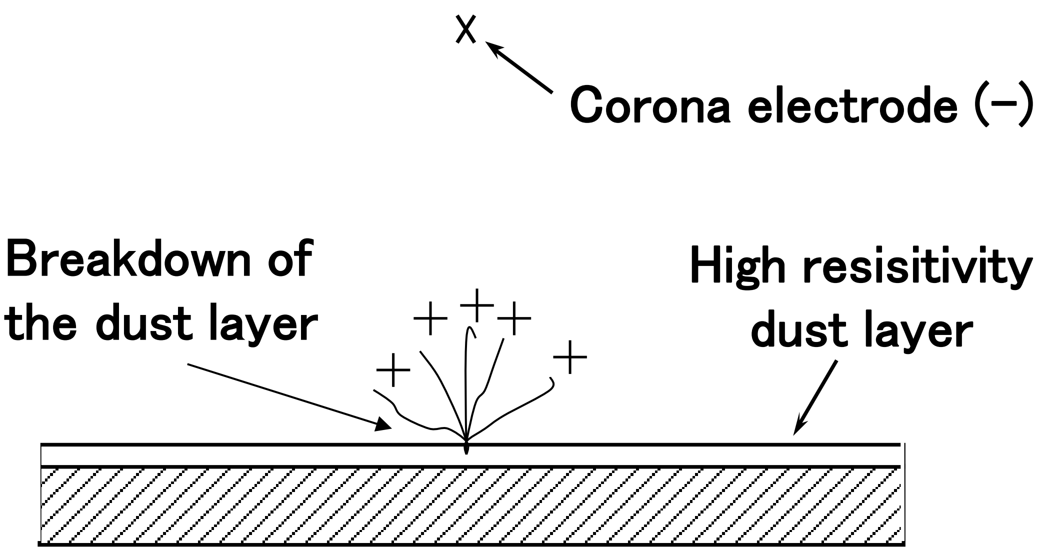
Effect of apparent dust resistivity on collection efficiency

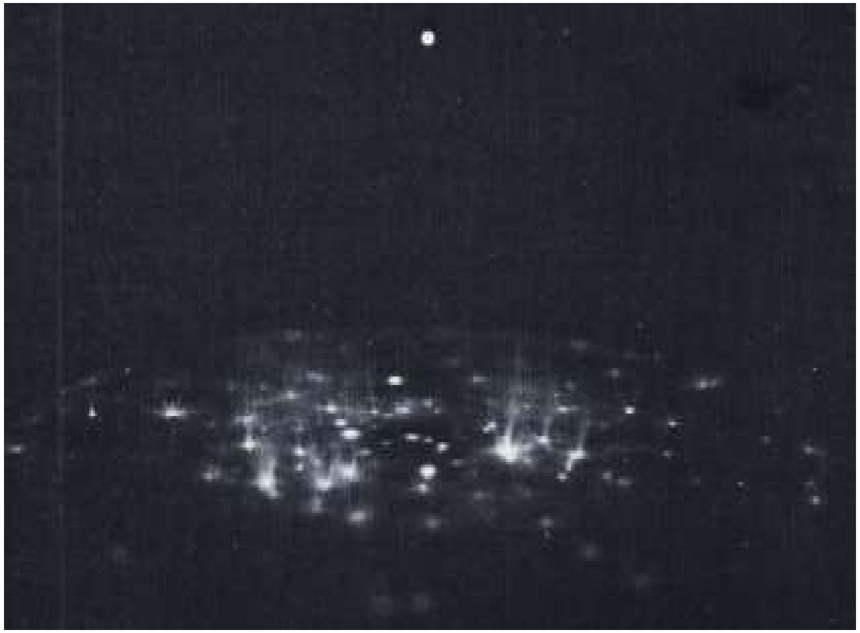


Back Corona

Electrical breakdown of high resistivity dust layer

- Generation of ions of opposite polarity, increase in current
- Reduction of flashover voltage; Vf (positive) << Vf (negative)

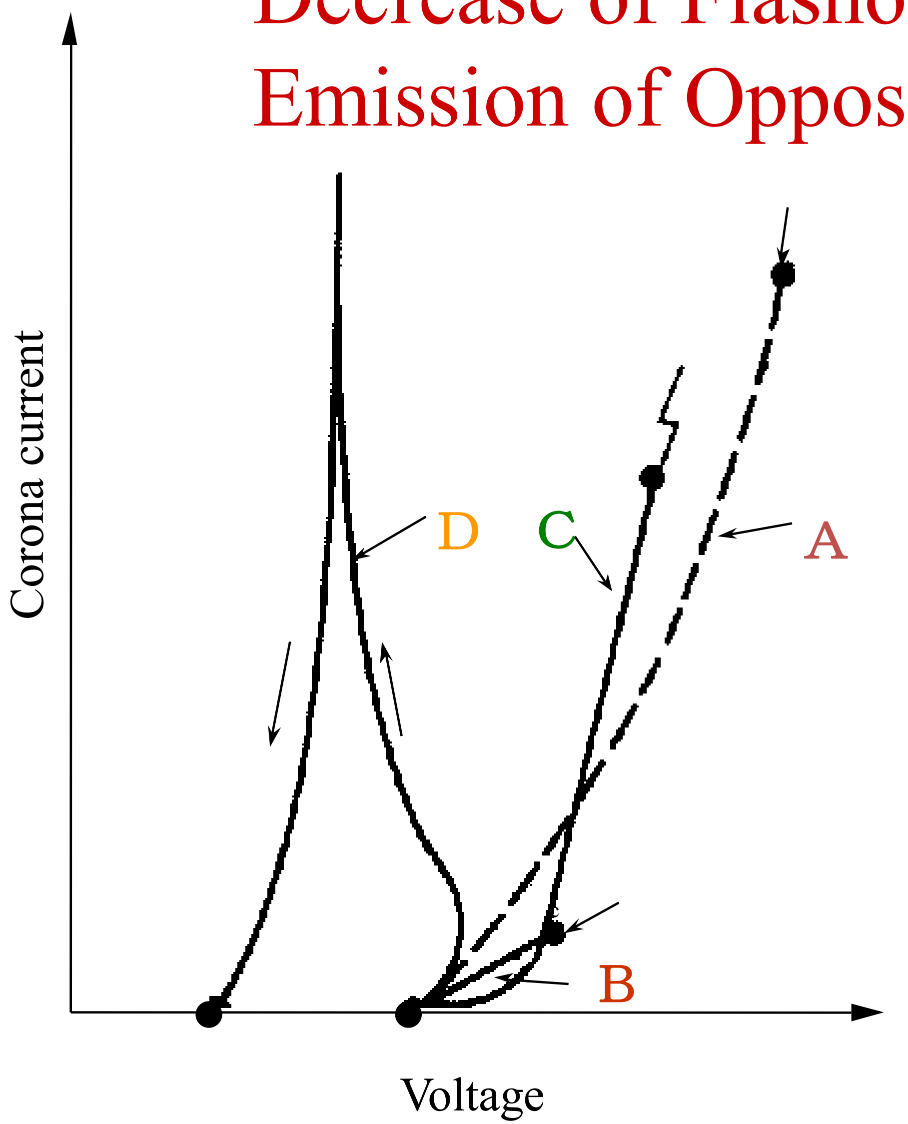




Back Corona

Decrease of Flashover Voltage

Emission of Opposite Ions



A： Normal

B： Excessive Sparking

C： Transition to Glow mode

D： Glow mode back corona

Abatement of Back Corona in industrial ESP's by control of energization

- Pulse Energization
- Intermittent Energization

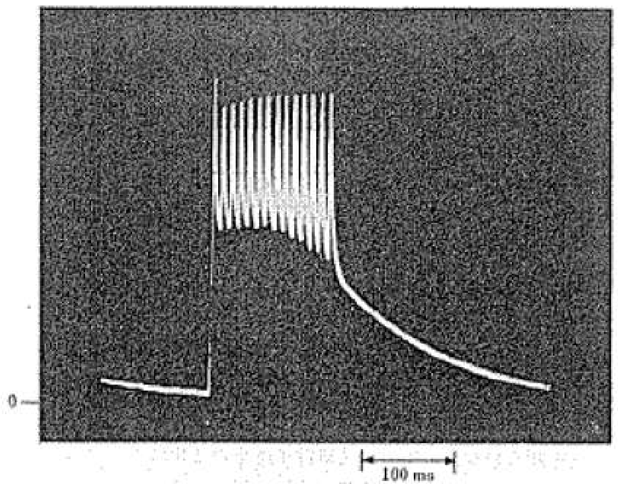
Uniform current distribution

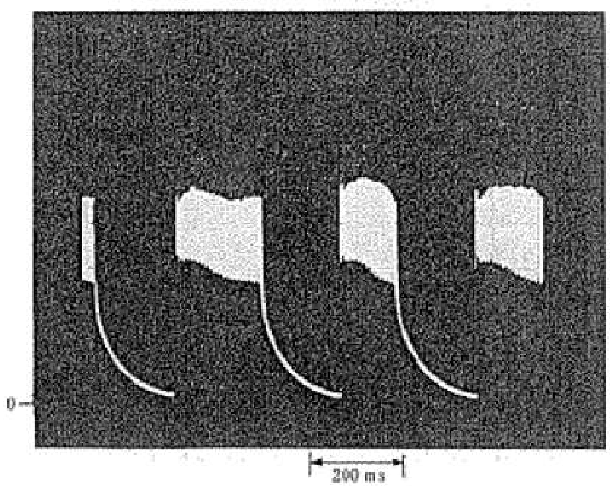
Lower the local surface-charge build-up of dust layer in front of corona electrode

Control of Voltage waveform for Back corona

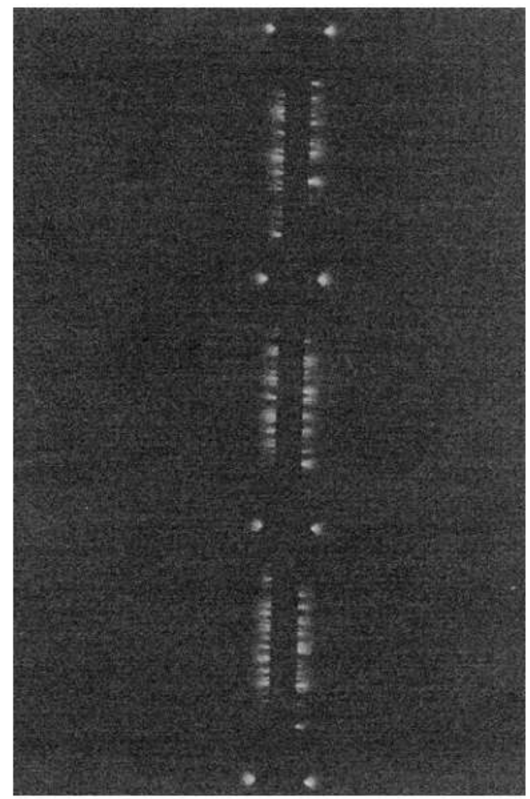
(Sumitomo-Heavy Industries)

Pulse voltage





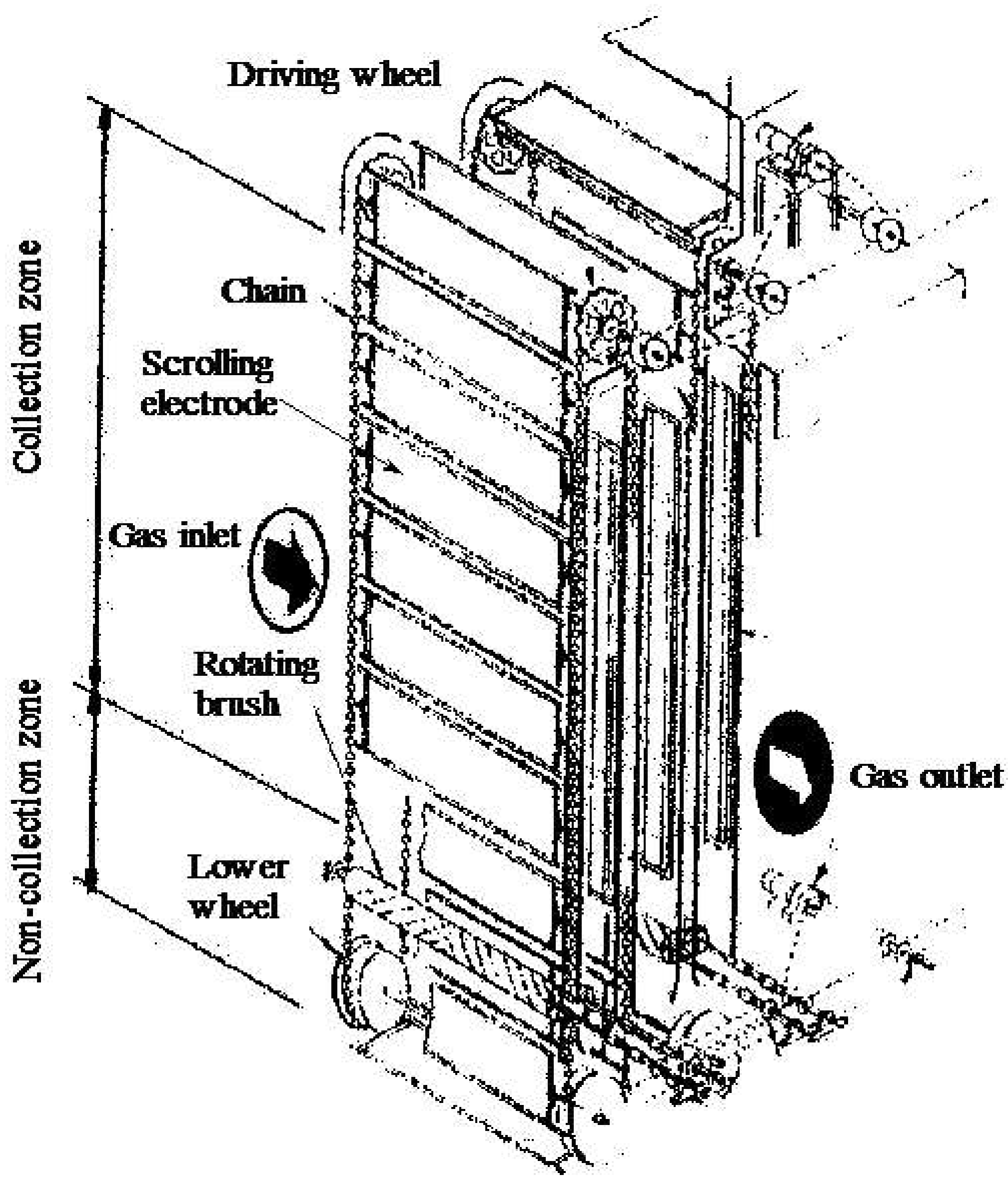
Pulsed corona
(more uniformgrow due to
higher peak voltage of pulse)



Comparison of the performance with DC and Pulse energization

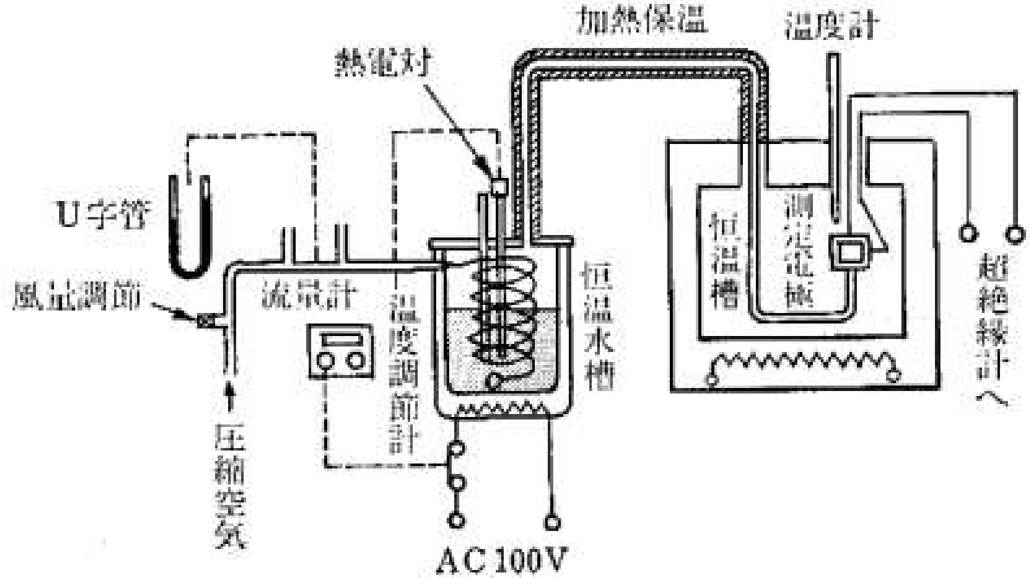
Different mixture of coal	Gas temp. (°C)	Apparent dust resistivity (Ωm)	Energization	Inlet dust concentration (g/m^3)	Outlet dust concentration (g/m^3)	Power consumption (kWh)
A	120	9.4×10^9	DC	13.3	30	8.5
[redacted]						
B	123	1.5×10^{10}	DC	16.2	80	6.2
[redacted]						
C	124	2.5×10^{10}	DC	20.5	147	4.5
[redacted]						

Moving belt-type ESP

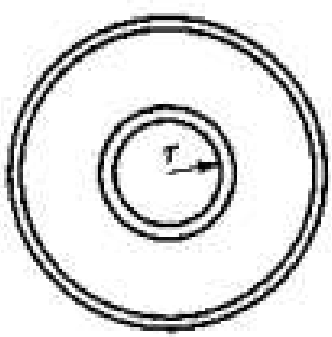


Dust deposition is constantly scraped off to avoid back corona.

Measurement method of Apparent dust resistivity (JIS 9910)



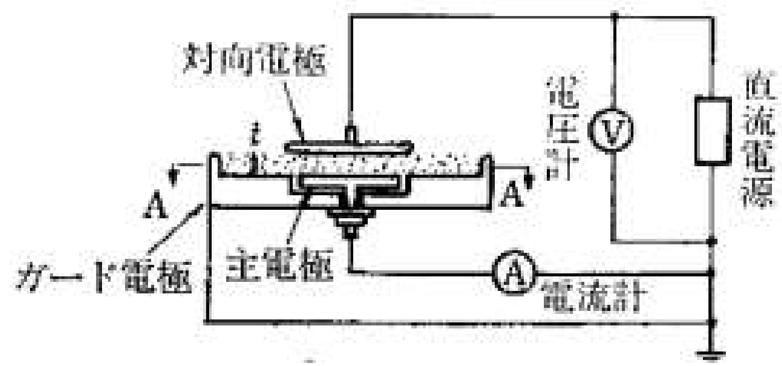
Use of a chamber with constant temperature and humidity



$$R = \frac{\pi r^2}{t} \cdot \frac{V}{I}$$

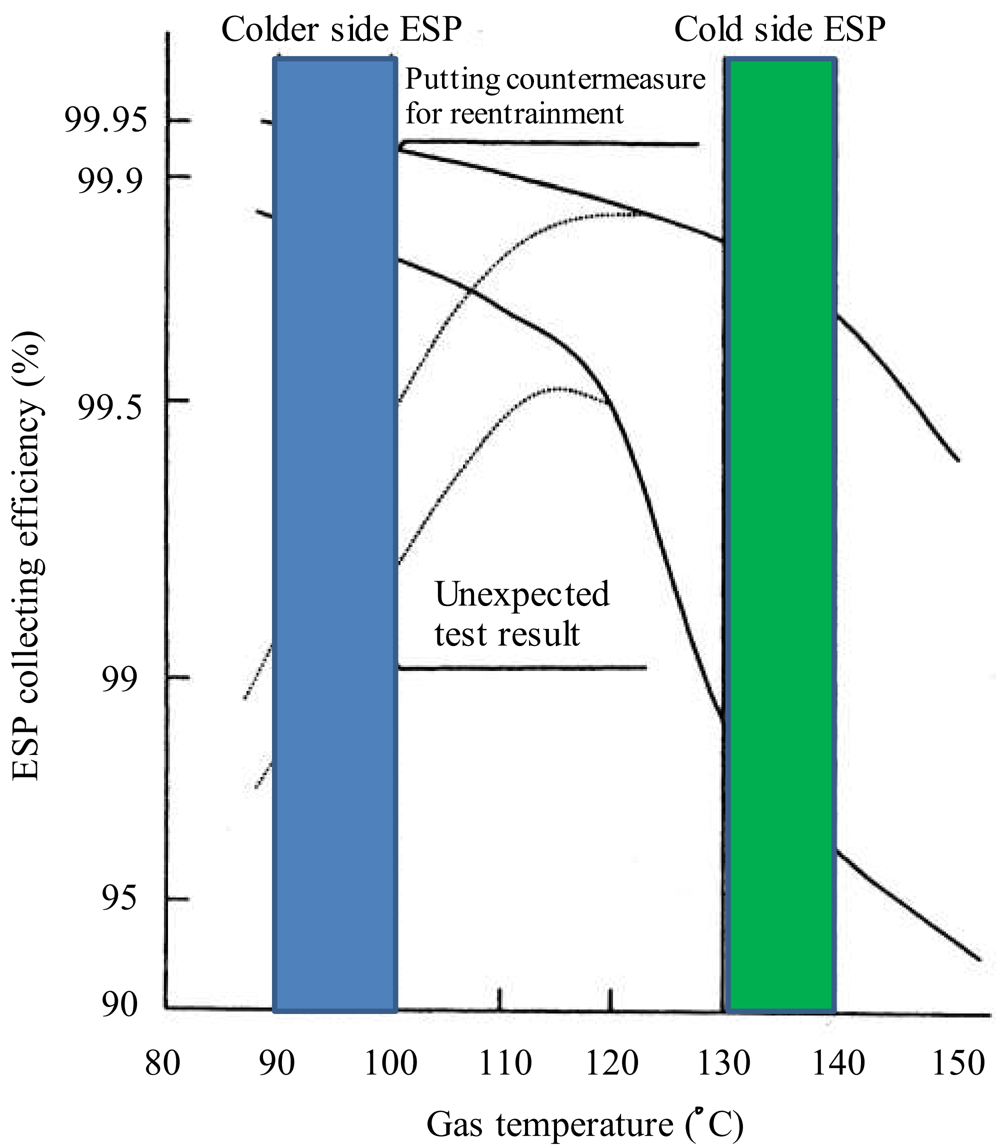
A-A断面

Electrode



Measuring circuit

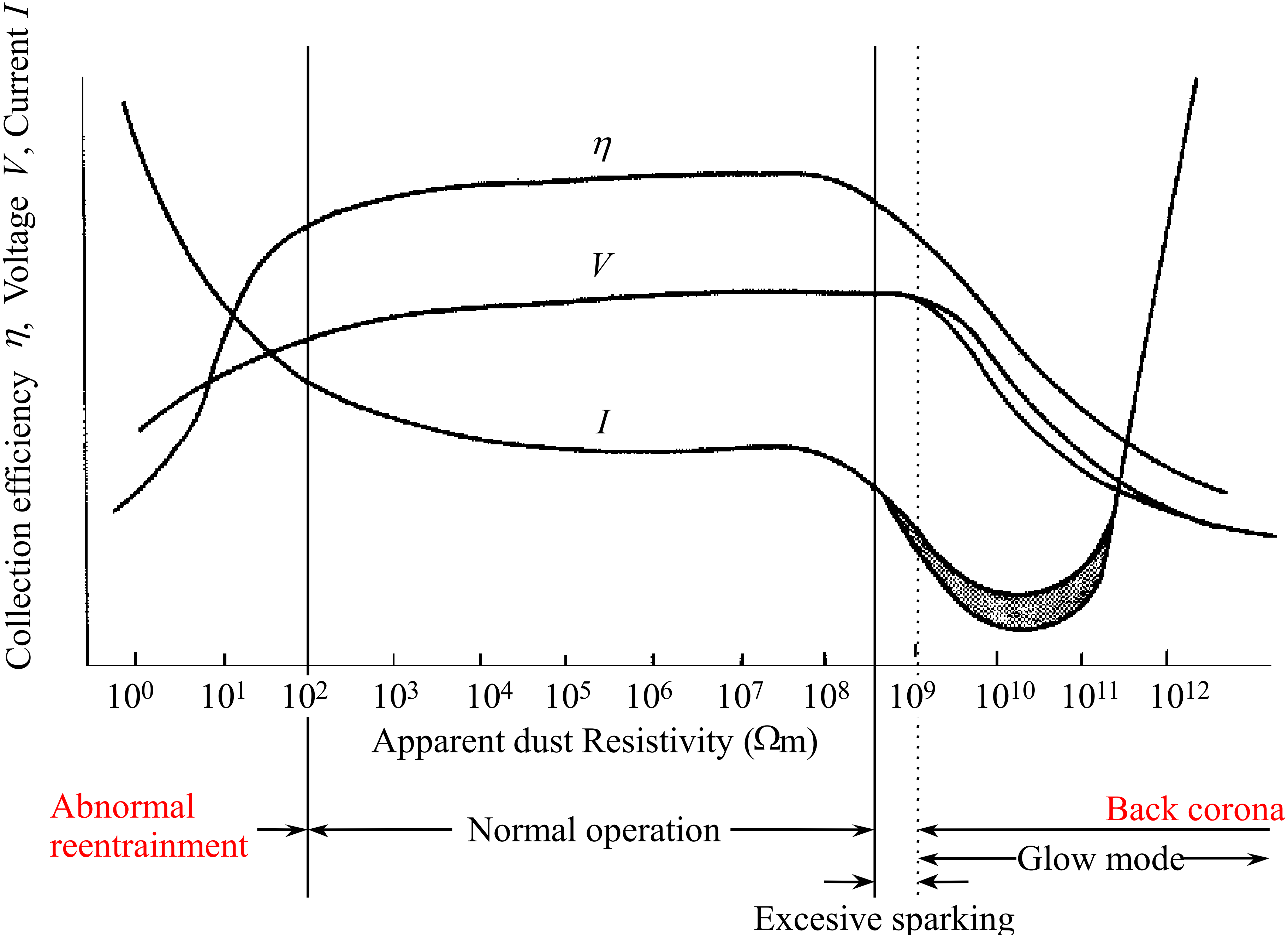
Gas temperature vs. collection efficiency



Reduce the operating temperature to decrease the resistivity. Anti-corrosion care must be taken.

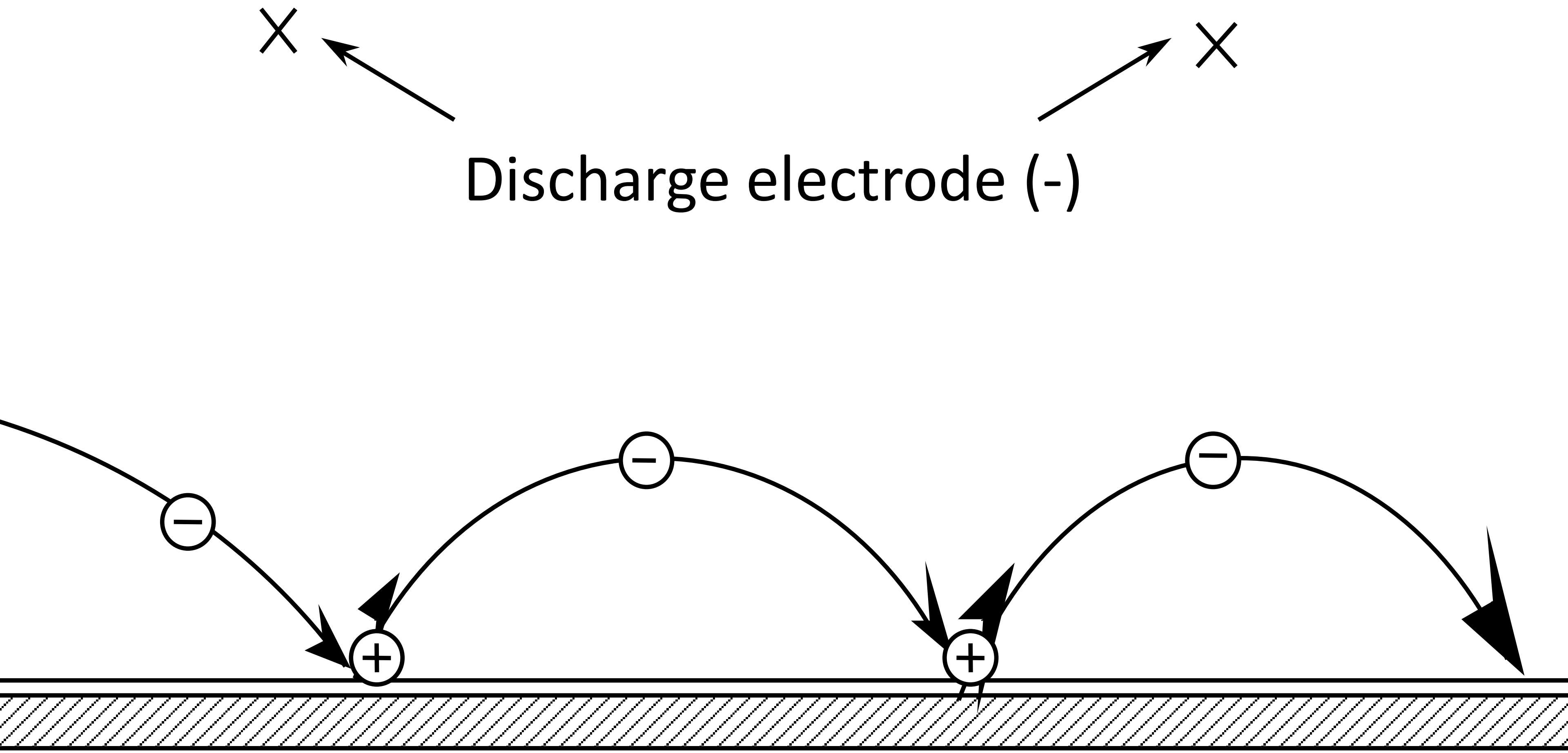
Blending different kind of coal is also effective to avoid back corona.

Effect of apparent dust resistivity on collection efficiency



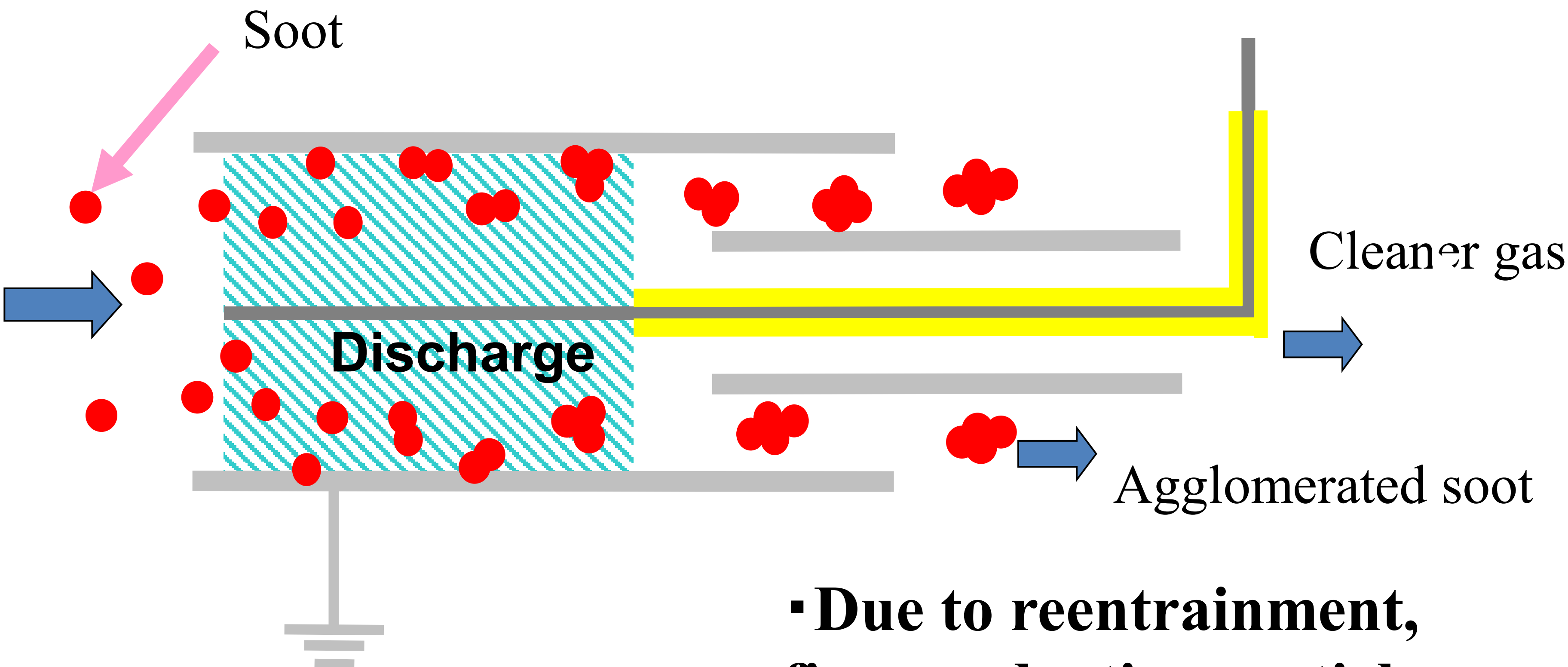
Abnormal Dust Re-entrainment

Low resistivity dust acquires the opposite charge by induction charging and pulled back to space, jumping away



Diesel Soot Agglomeration

(Utilization of abnormal reentrainment)



▪**Due to reentrainment, fine conductive particles become large**

Features of Electrode System of Tunnel ESP

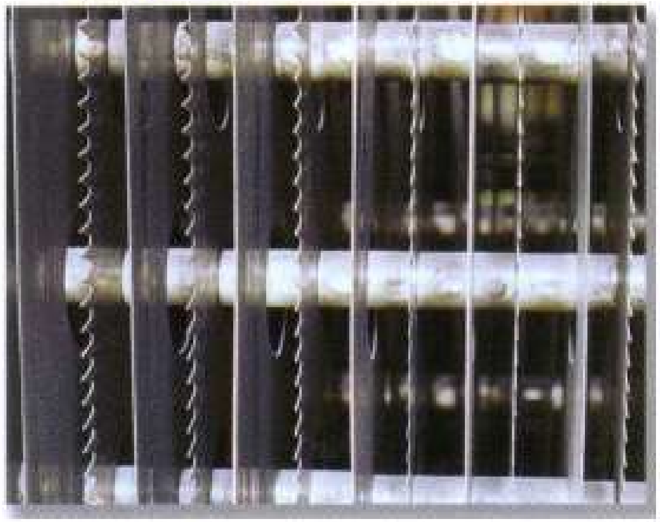
Very fine diesel particulate shall be removed.

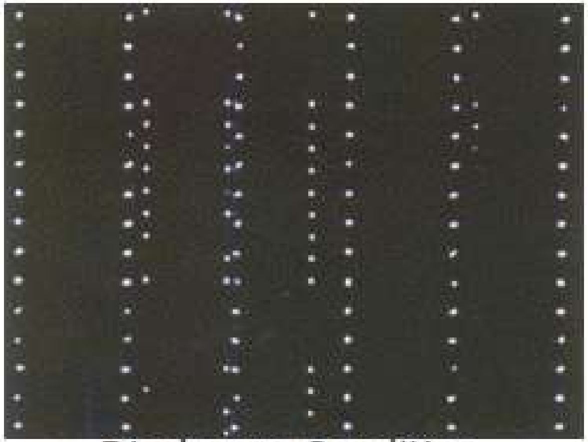
Ventilation air flow is huge. (typically > 100 m^3/s)

⇨ Air flow velocity in ESP shall be typically > 10 m/s.

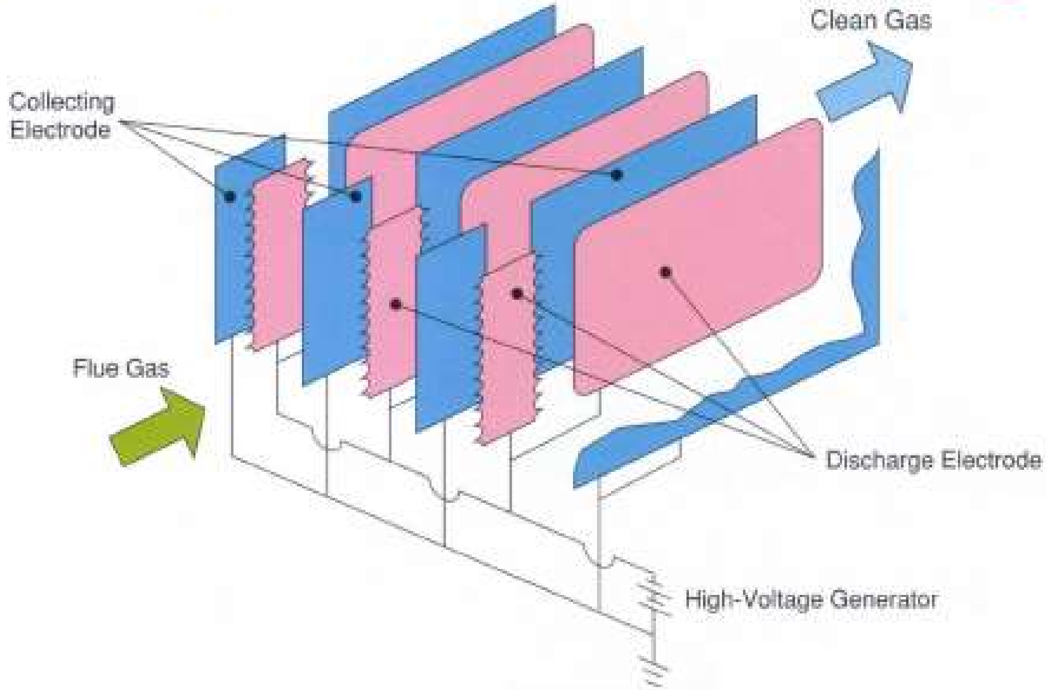
More than 80% efficiency is required. (< 1mg/m^3N outlet)

⇨ Specially designed electrode system with narrow spacing





Discharge Condition

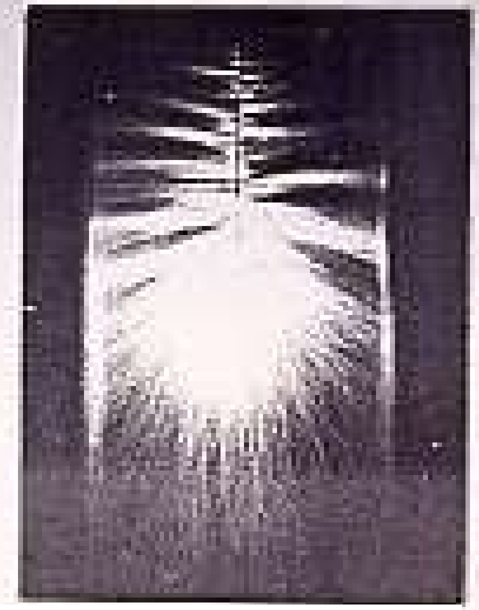


MHI Co. Ltd

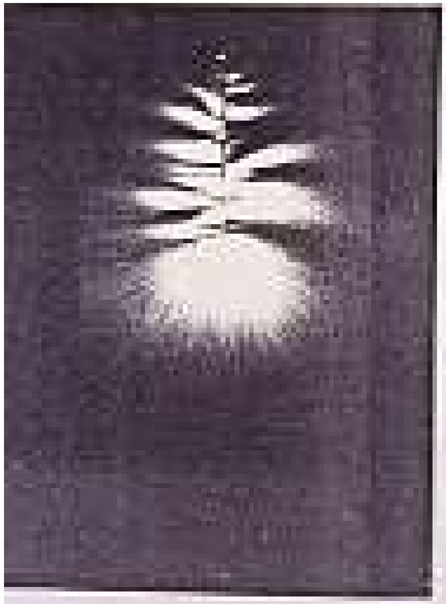
Positive pulsed discharge in needle-plate electrode

Gap: 80 mm,
Pulse peak voltage: 50 kV
Tr: pulse rising rate

Tr: 1.0 kV/ns



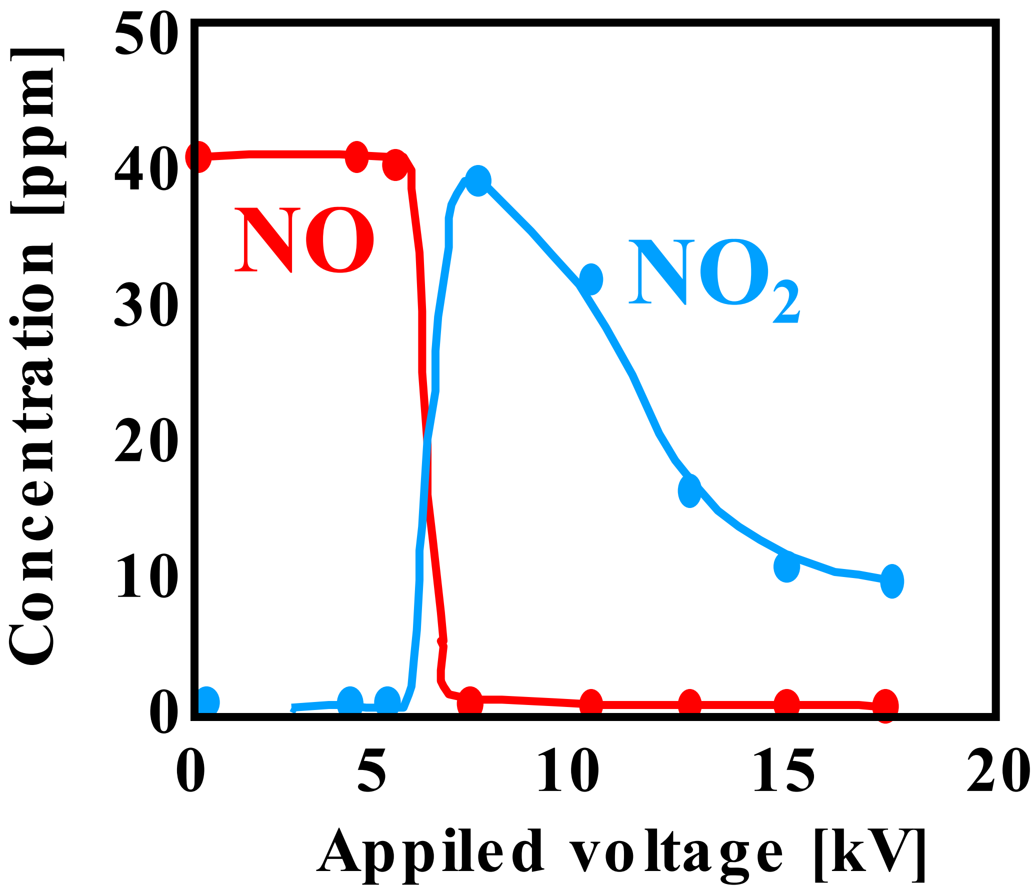
Tr: 0.3 kV/ns



Tr: 0.05 kV/ns

Fig. 6 Positive pulsed streamer corona discharge (Pulse peak voltage:+50 kV, Electrode separation:80 mm, Tr:Pulse rising rate)

Oxidation of NO in air with pulsed streamer discharge



Treatment time:0.6 sec

Non-thermal plasma chemical process

Advantage:

Low temperature process

Disadvantage

Low Selectivity and Low energy efficiency

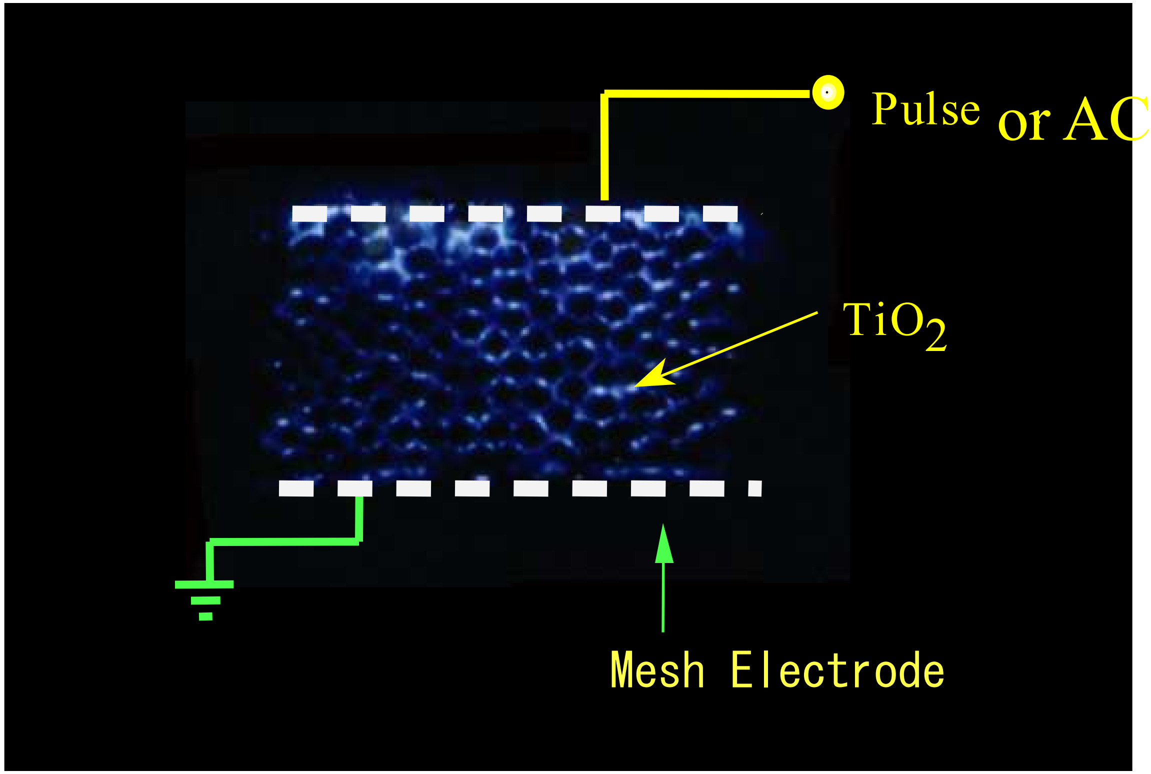
To improve:

Combine with catalyst or adsorbing surface

Increasing E/N + Keep pollutant molecules for longer time on the surface exposed to NTP to have more chance for chemical reactions

(Mechanism of the synergetic effects still to be studied)

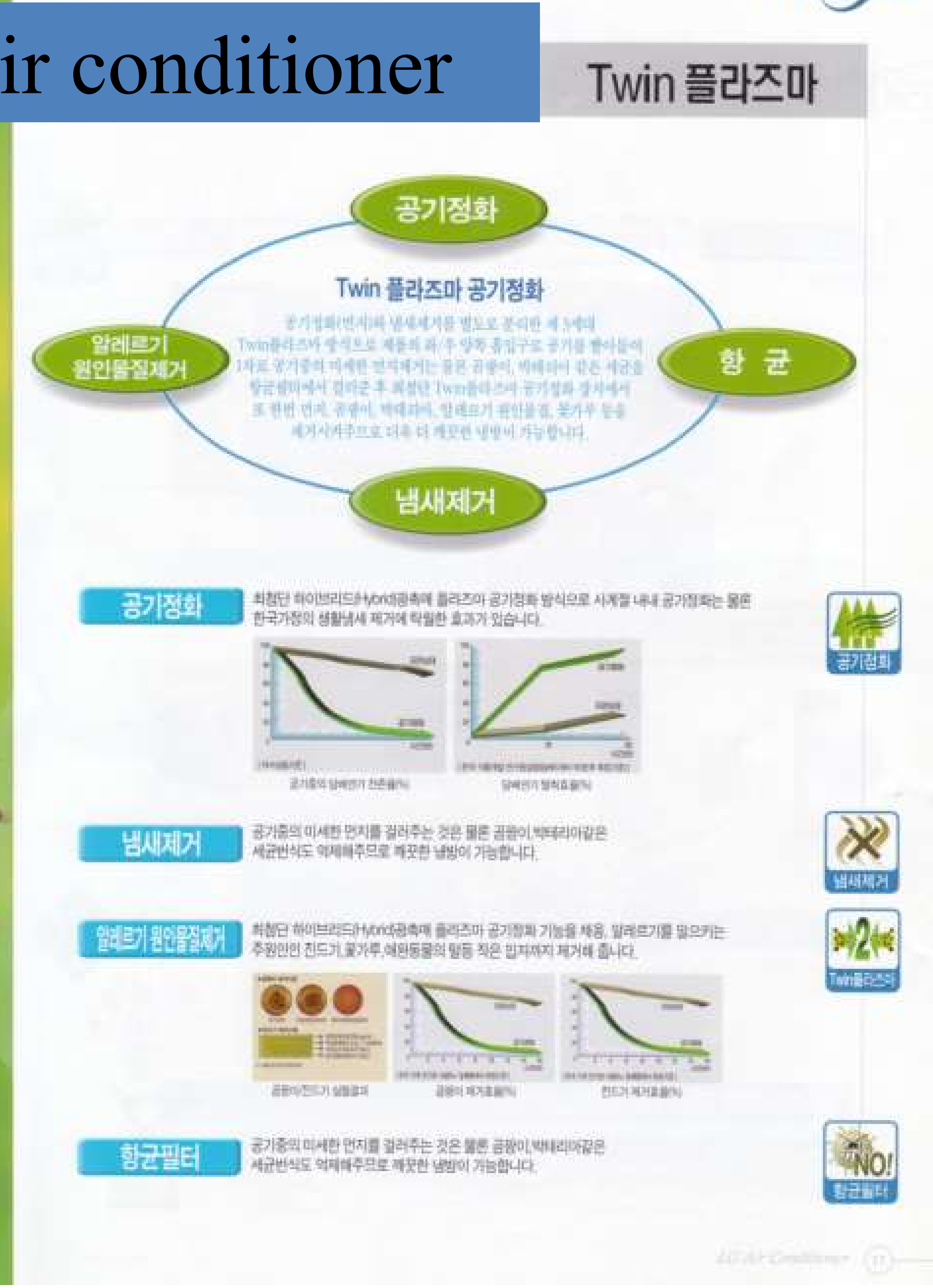
Packed bed with TiO_2 pellets



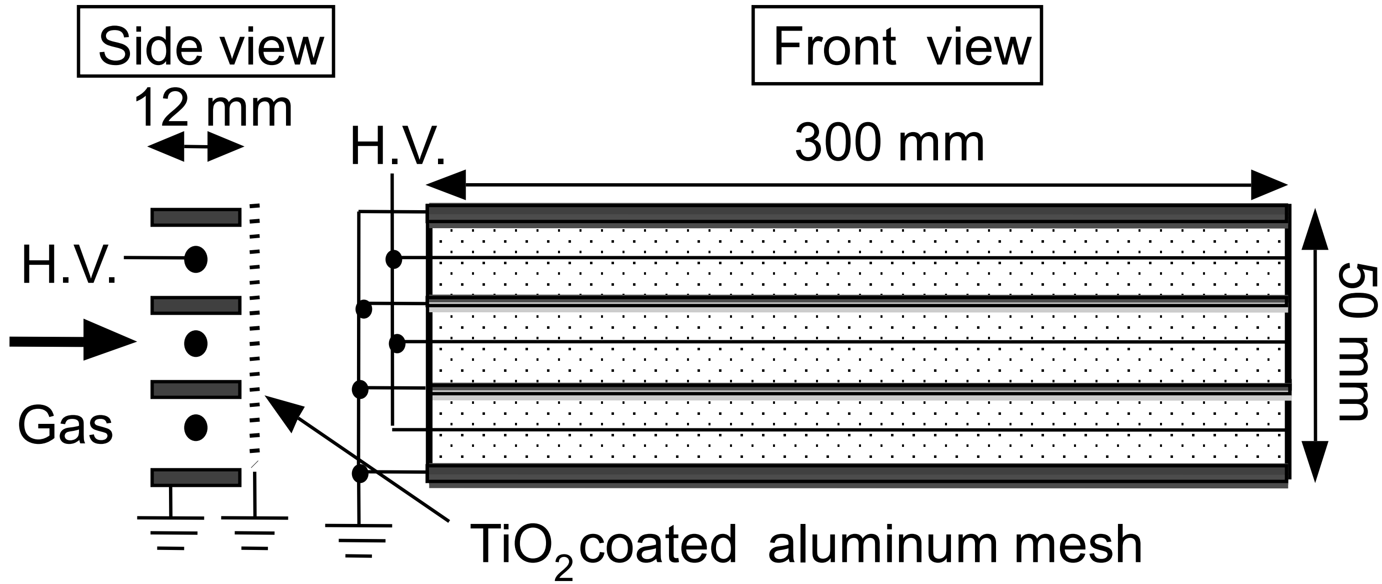
Packed-Bed Type Reactor

LG Electronics

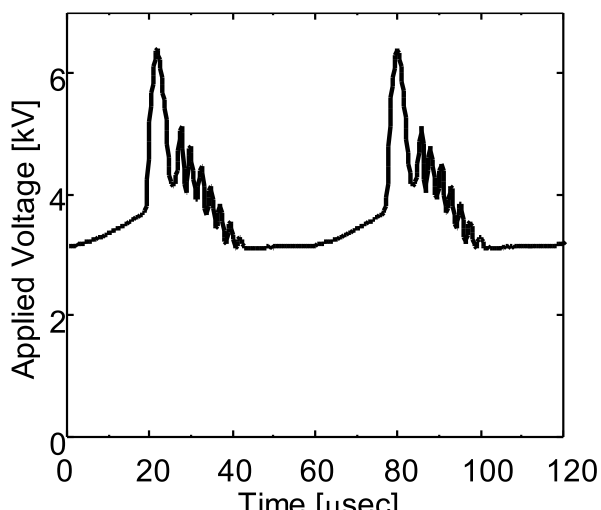
Plasma air cleaner for air conditioner



Plasma reactor combined with TiO_2 photocatalyst



(a) Setup of plasma reactor combined with TiO2



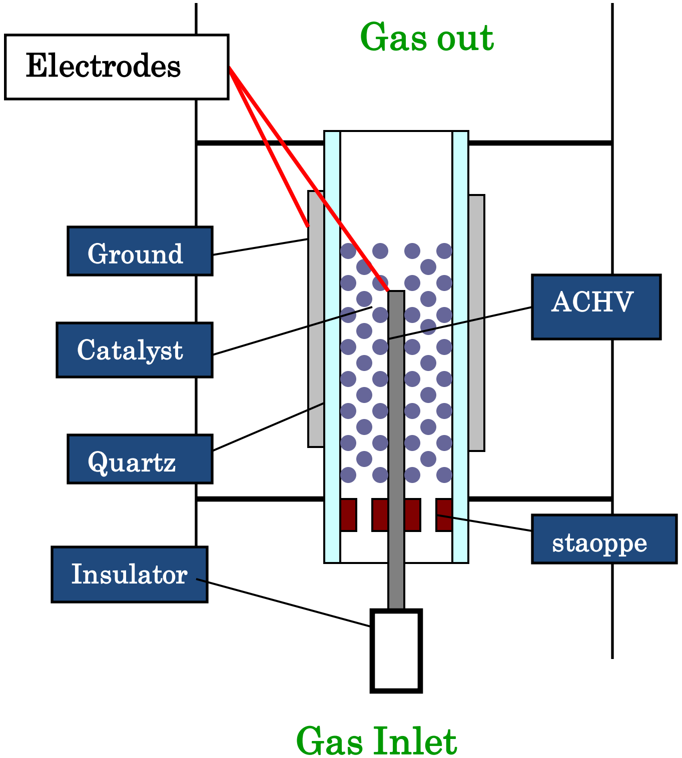
(b) Waveform of pulse voltage

Pulse is superimposed to dc voltage

VOC (Volatile Organic Compound) removal apparatus

- **Gas flow rate ： ６０ m³/min**
- **Max VOC concentration ： １５０ ppm**
- **Odor removal efficiency ： ８０ %**
- **Power consumption ： １２ Ｋw**
- **Weight ： ５４０ ｋｇ**
- **W×L×H ： 1140×754×1960 mm**

Packed Bed for Plasma-Assisted Combustion



- 30 kHz AC high voltage

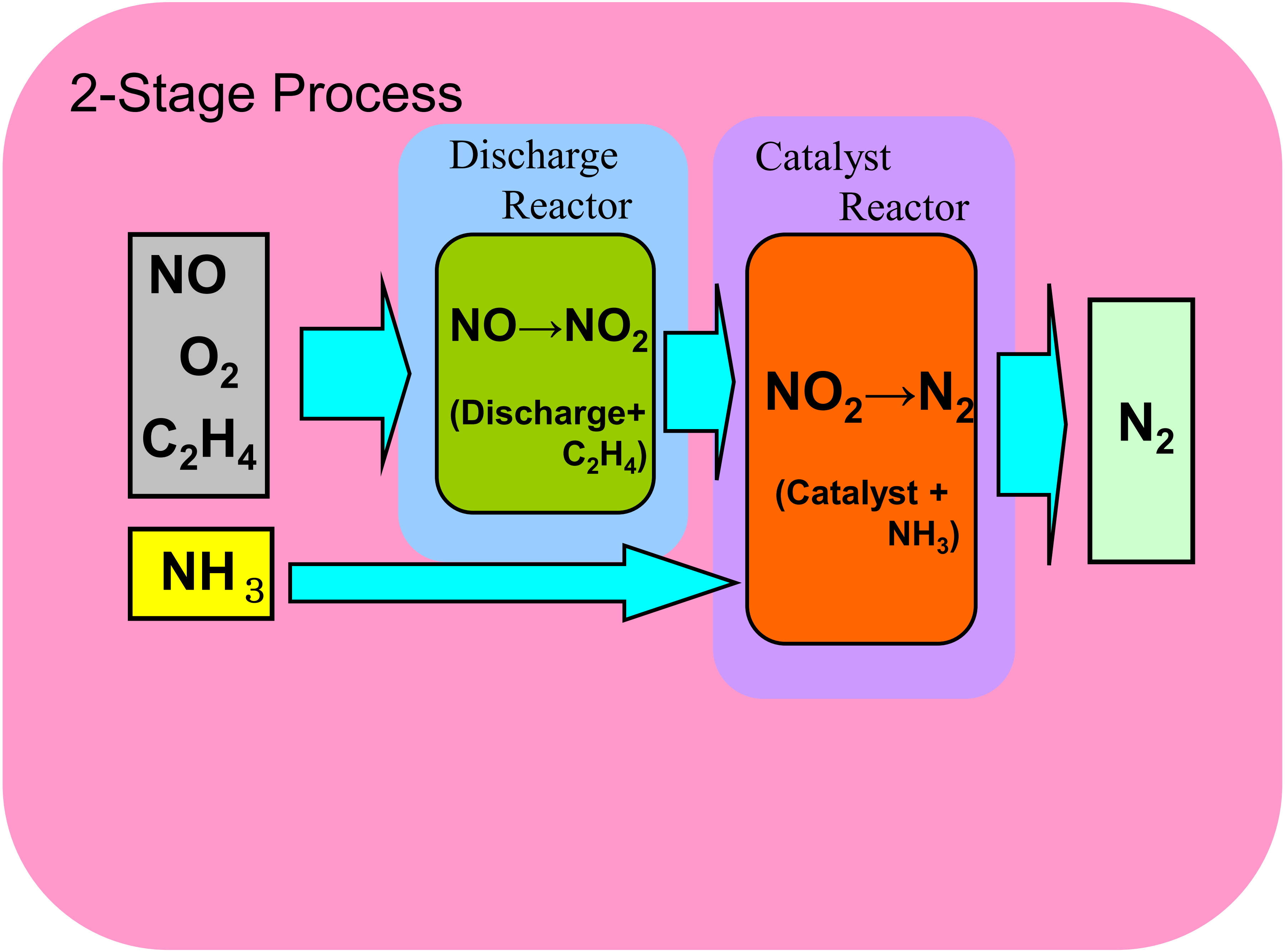
  Vp-p: 10 kV

- Pt Catalyst + Plasma
- Heating by plasma

Plasma-assisted combustion

Operating temperature: 200 - 400 C

Typically 2000 ppm of Toluen can be completely oxidized to CO_2 and H2O with 10 ms detention time in the plasma section


2-Stage Process
Discharge Reactor
Catalyst Reactor
NO
O2
C2H4
NH3
NO→NO2
(Discharge+ C2H4)
NO2→N2
(Catalyst + NH3)
N2

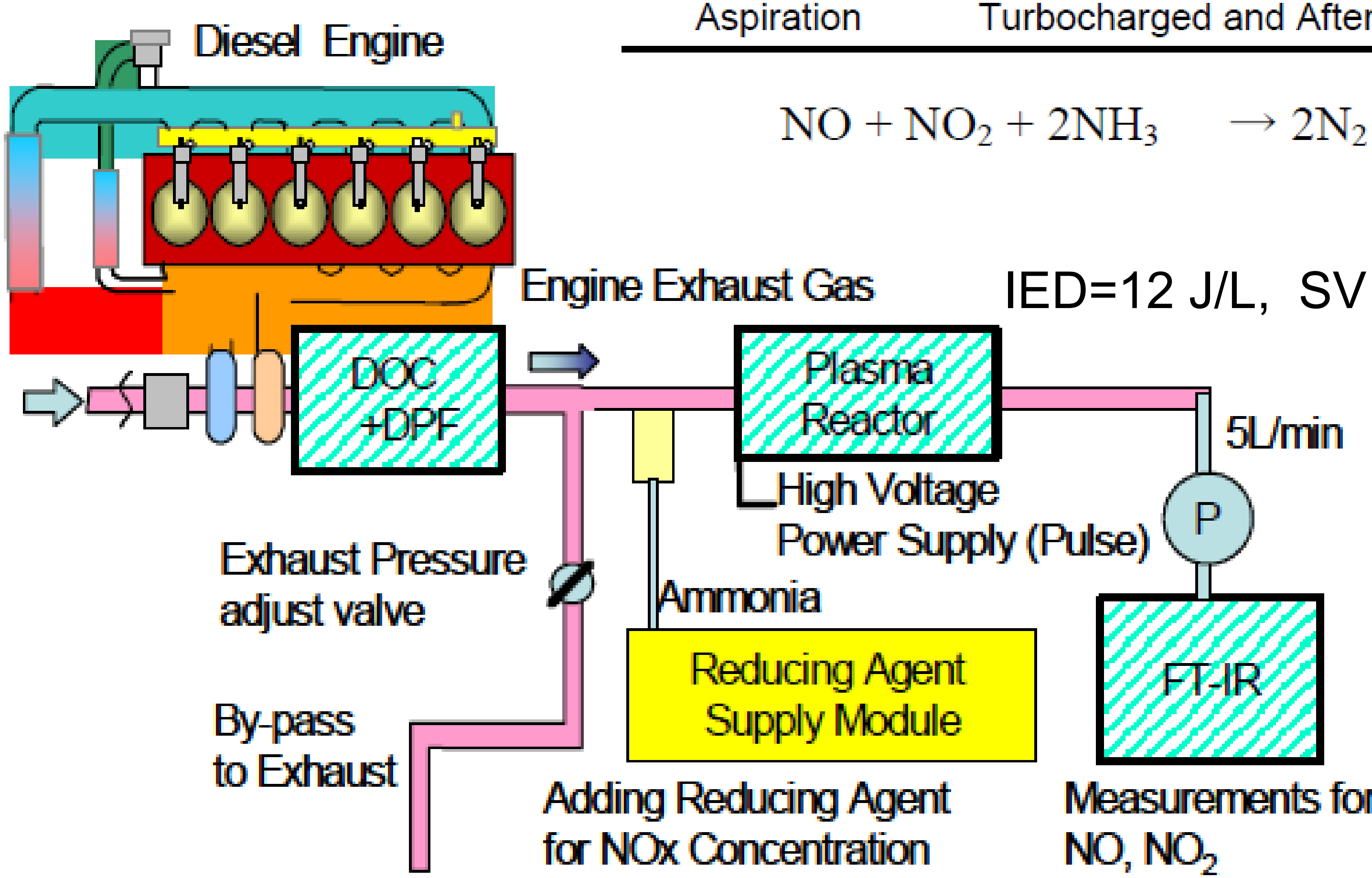
DeNOx for Diesel exhaust using Test bench with JE05 mode (Sato, et al. SAE 2011)

Table .1 Specifications of Test Engine

Item	Specification
Engine Type	6 cylinder DI
Displacement	7.684 liter
Bore & Stroke	112mm × 130mm
Aspiration	Turbocharged and Aftercooled

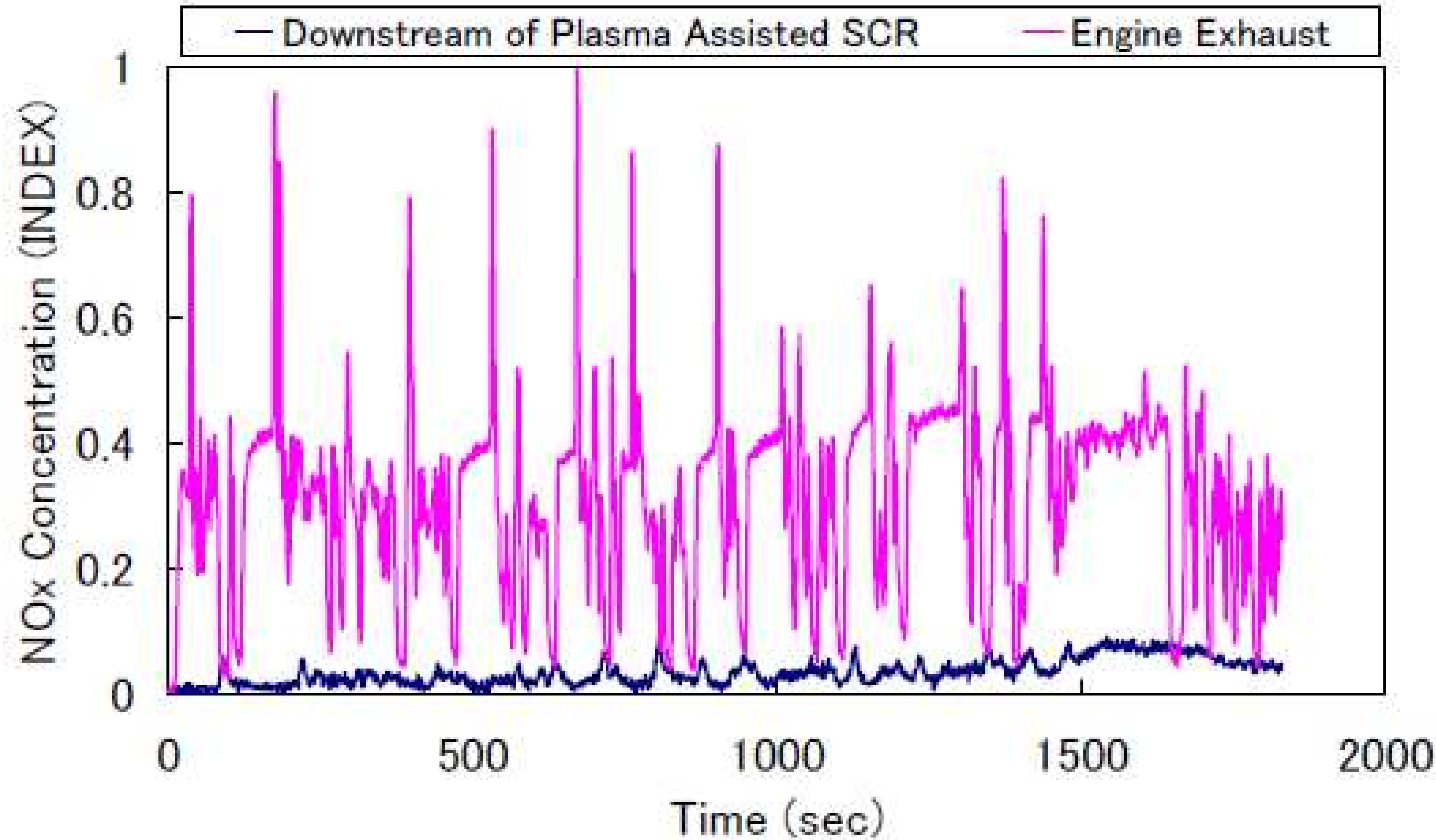
$$NO + NO_2 + 2NH_3 \rightarrow 2N_2 + 3H_2O$$

IED=12 J/L, SV 25,000 h^{-1}



(Background slide 2)

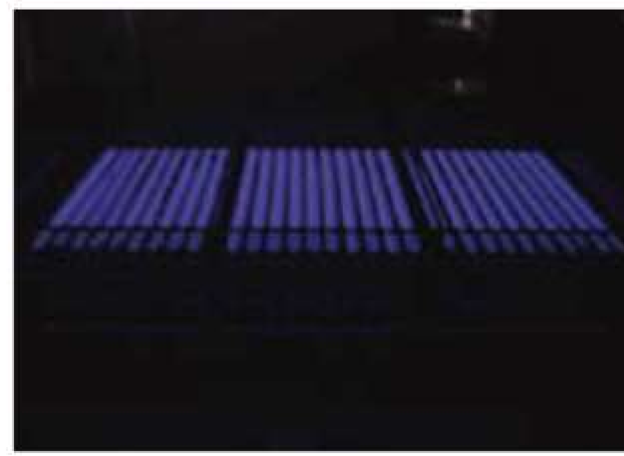
Comparison of the Instantaneous NOx Concentration at Inlet and at Outlet of the Plasma Reactor (Sato, et al. SAE 2011)



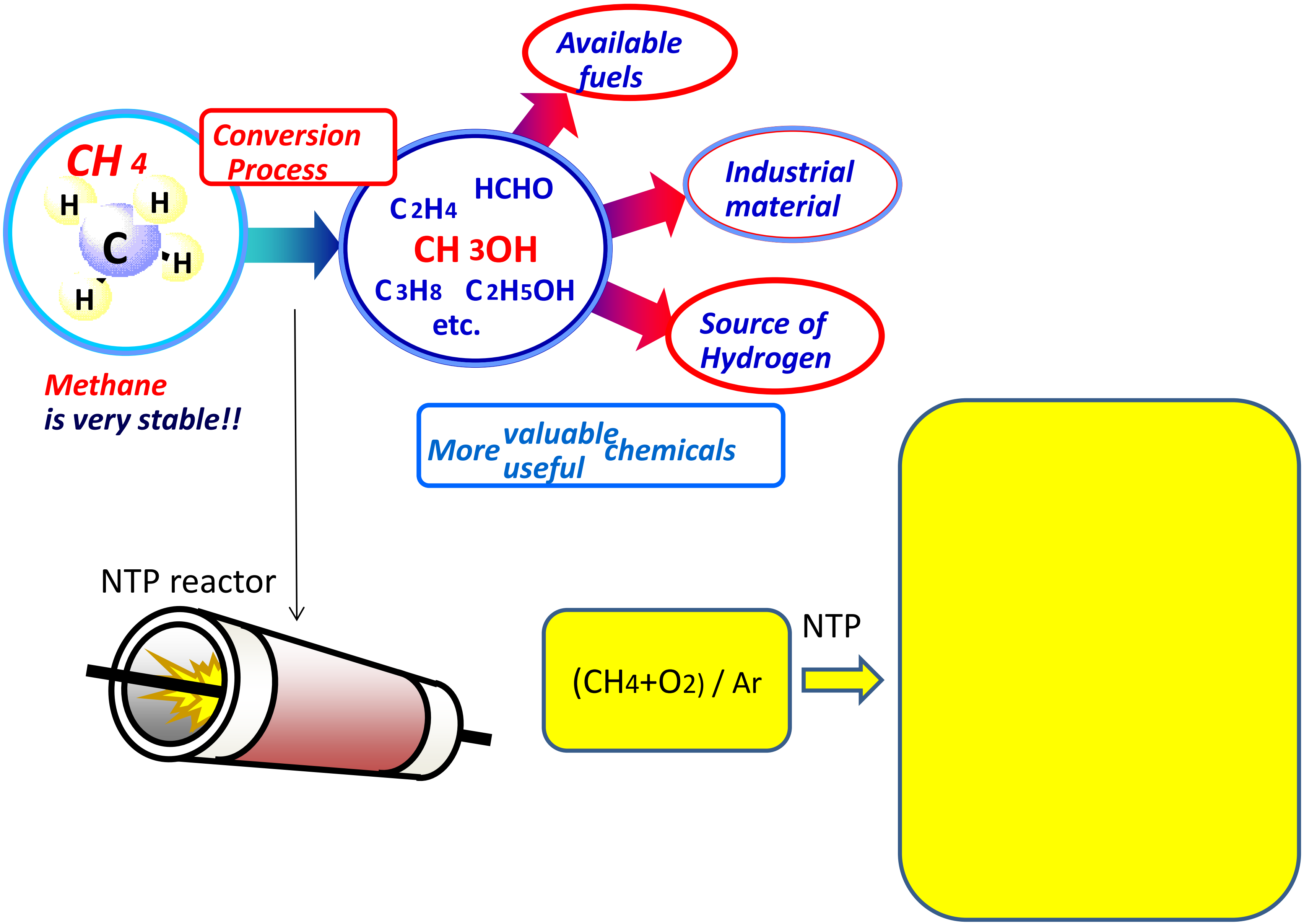
Air cleaning apparatus for smoking room
(Nittetsu Mining Co., Ltd)

Particle, odor, and CO removal

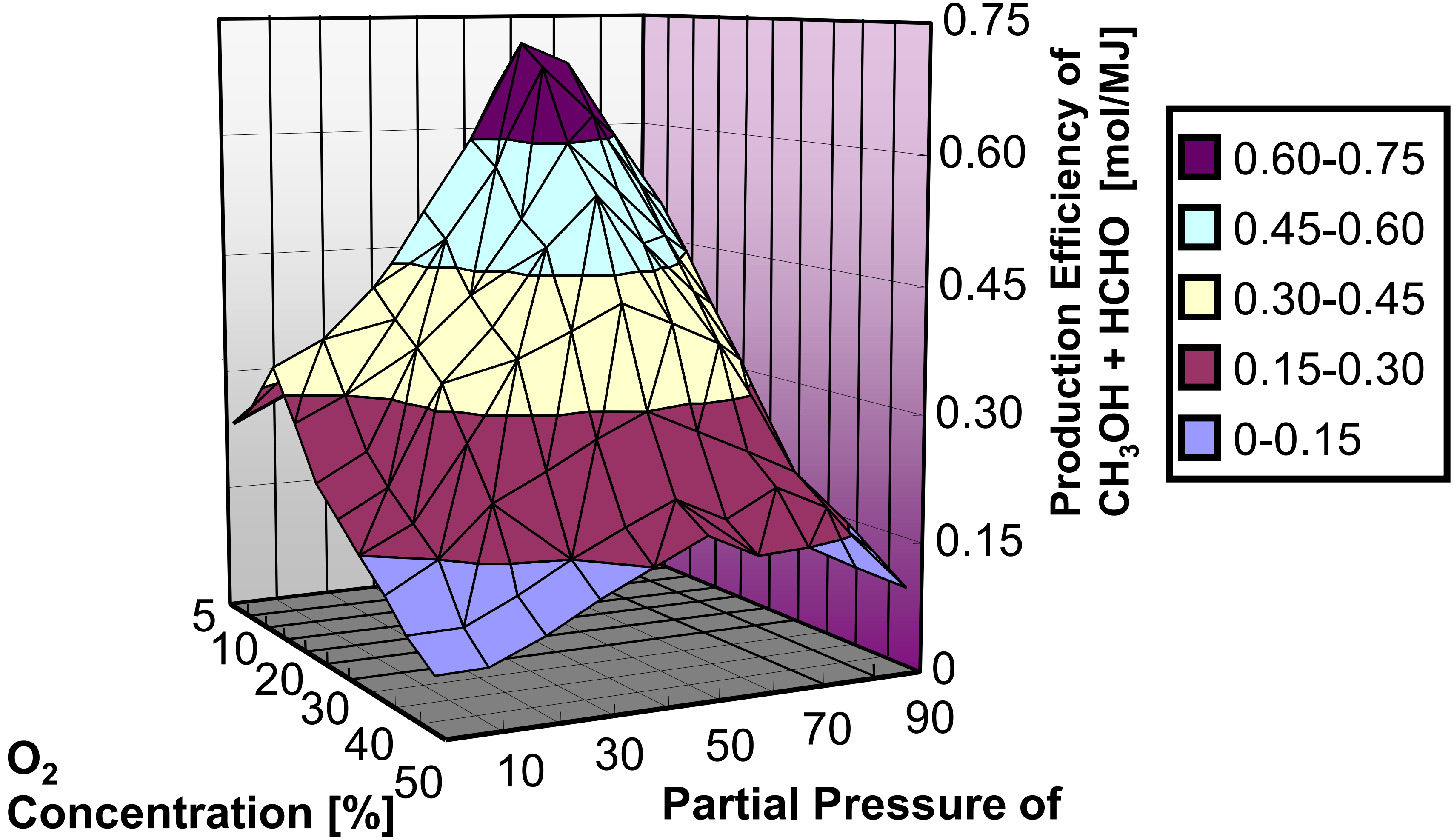
1. Pre-and HEPA filter
2. Plasma (DBD)
3. Catalyst



Conversion of METHANE by NTP

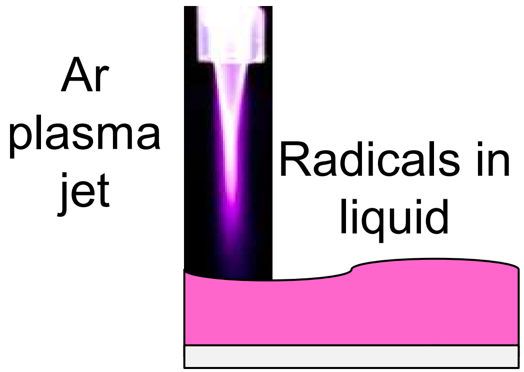


Production efficiency of methanol vs. Oxigen concentration and Ar partial pressure



SIE: 360 J /L

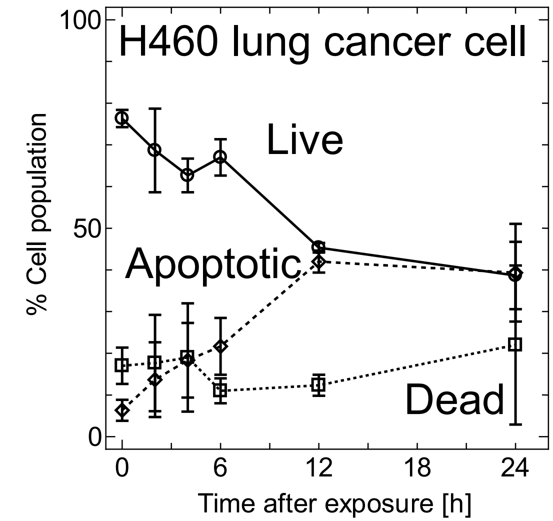
Biological Applications
(Sterilization, Surface modification, Plasma medicine, etc.)

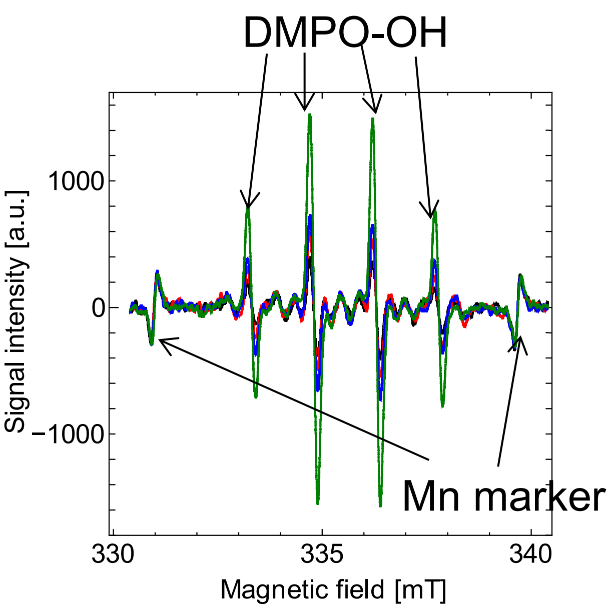


Apoptosis induction

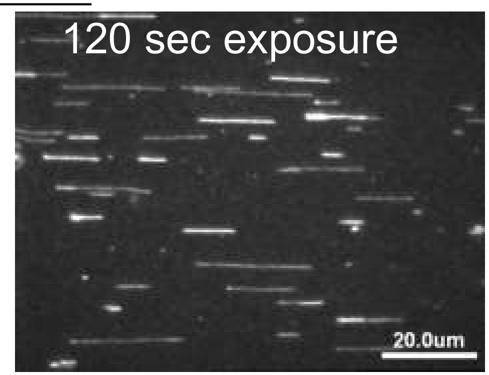
DNA damage

ESR measurement



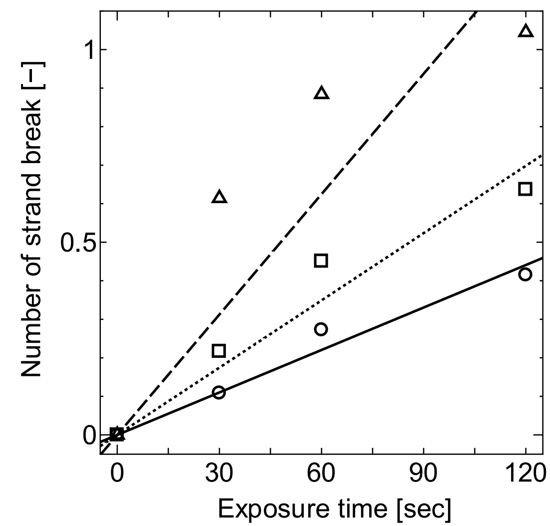


DNA fragmentation method
for quantify the reactivity of radicals



(Single-molecule DNA imaging)

Number of strand breaks



H. Kurita, *et al.*, *Appl. Phys. Lett.*, **99**, 191504 (3 pp.), 2011

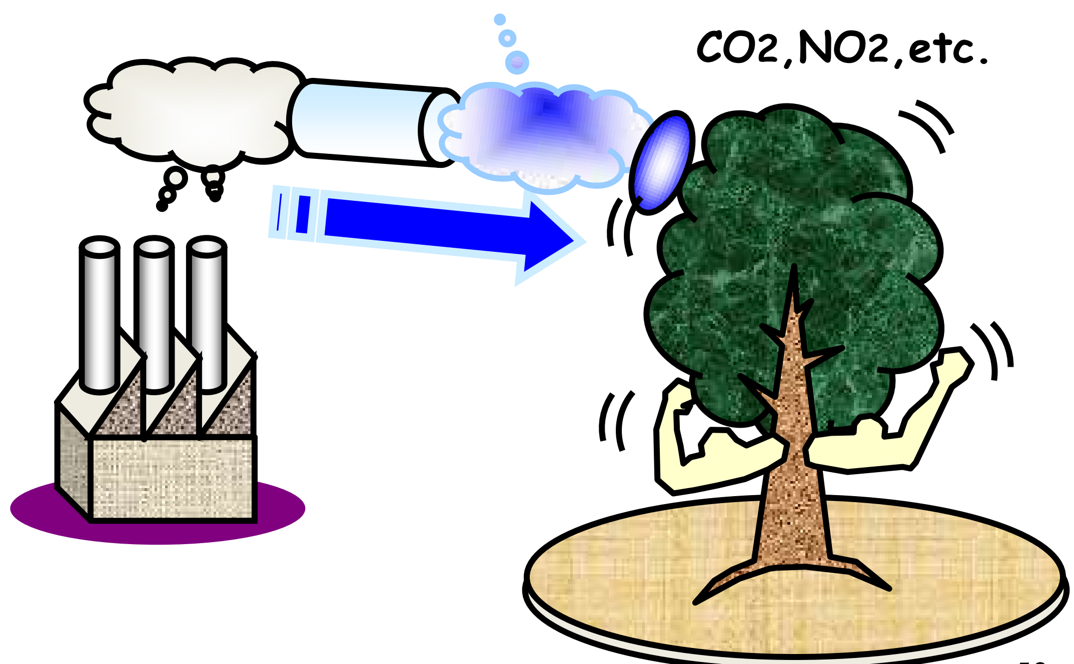
ICPM-5: 19-P02-06, 20-BO08

Exhaust Gas *---*

Conventional aspect: dirty

From the other aspect: Biologically clean, and is an important resource for agriculture, as it contains CO_2, H_2O, NOx and SOx (fertilizer for plants)

Heavy metal and VOC are major pollutants when utilizing exhaust gas in green house. Those should be controlled in future.



Concluding Remarks

- Electrostatic precipitators is an old technology, but there are various new applications for improving our health and environment.

- Non-thermal plasma-catalyst process is effective to generate reactive radicals that promote chemical reactions at lower temperature.

- NTP processes are expected to be more competitive in fuel processing, since renewable electricity has been rapidly increasing and surplus electricity will be available.