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미세먼지 해결을 위한 기계기술

2019 글로벌 기계기술 포럼

2019. 9. 4. (수)
13:00~17:00

국회도서관 강당

| 주최 | KIMM 한국기계연구원 KOREA INSTITUTE OF MACHINERY & MATERIALS 더불어민주당 이상민 국회의원 자유한국당 정용기 국회의원

| 후원 | 과학기술정보통신부 Ministry of Science and ICT nst 국가과학기술연구회 National Research Council of Science & Technology

https://forum.kimm.re.kr

미 세 먼 지 해결을 위한 기 계 기 술

2019
글로벌 기계기술 포럼

2019. 9. 4.(수) 국회도서관 강당

주 최

KIMM 한국기계연구원 KOREA INSTITUTE OF MACHINERY & MATERIALS

더불어민주당 이상민 국회의원

자유한국당 정용기 국회의원

후 원

과학기술정보통신부 Ministry of Science and ICT

nst 국가과학기술연구회 National Research Council of Science & Technology

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인 사 말 씀

KIMM 한국기계연구원
KOREA INSTITUTE OF MACHINERY & MATERIALS

원장 박 천 홍

한국기계연구원은 2017년 기계 산업의 글로벌 아젠다로 4차 산업혁명과 국방기술, 기후변화체제를 설정하고 앞서 두 번의 포럼을 개최하였습니다. 그 사이 우리 사회는 각각의 아젠다를 둘러싸고 큰 변화의 물결을 맞았습니다.

올해는 마지막 아젠다인 기후변화 체제를 논의하기 위해 '미세먼지 해결을 위한 기계기술'을 주제로 포럼을 준비하였습니다.

오늘 포럼에는 독일과 일본, 중국 등 세계 각국의 전문가가 참석해 미세먼지 문제를 먼저 겪은 나라의 입장에서, 또 앞으로 함께 미세먼지 문제를 해결해가야 할 입장에서 어떤 준비가 필요할지 허심탄회하게 논의하는 장이 될 것입니다. 기술이라는 공통 화두를 가지고 자유롭게 논의할 수 있다는 점이야말로 과학이 가진, 국경을 넘는 힘이 아닐까 합니다.

우리 연구원은 환경문제를 해결하기 위한 다양한 기계기술 연구개발에 매진하고 있습니다. 정전기를 이용한 초미세먼지 및 유해가스 처리 기술, 석탄 발전 시스템에서 발생하는 유해가스 처리기술, 플라즈마를 이용한 에너지 환경기술 등이 대표적인 사례들입니다.

최근에는 플라즈마 DPF 장치를 활용한 군용 차량의 매연 저감, 비도로 이동원에서 발생하는 미세먼지 저감 실증사업 등 환경 기계 기술을 우리 삶 속 다양한 분야에 적용하여 깨끗하고 안전한 환경을 만들기 위해 노력하고 있습니다.

우리는 과학기술이 우리 삶의 문제를 해결한다는 믿음을 갖고 있습니다. 오늘 이 자리에서 국내외 전문가를 모셔서 들어보는 시간과 함께 미세먼지 문제를 기계기술로 해결할 수 있는 비전을 제시하고자 합니다.

감사합니다.

인 사 말 씀

더불어민주당

더불어민주당 과학기술특별위원장 겸 정보통신특별위원회 위원장

이 상 민

존경하는 산 · 학 · 연 · 관 관계자 여러분. 국회의원 이상민입니다.

더운 날씨에도 불구하고 미세먼지 문제에 관심을 갖고 '2019 글로벌 기계기술 포럼'에 와주셔서 감사합니다. 함께 행사를 주최해주신 자유한국당 정용기 의원님과 한국기계연구원 박천홍 원장님 및 관계자 분들께도 감사 인사를 전합니다.

이번 포럼은 "미세먼지 해결을 위한 기계기술"을 주제로 한국과 중국을 비롯해 인도, 미국, 러시아까지 세계 각국에서 화두로 부상하고 있는 미세먼지 저감을 위해 다양한 분야의 전문가가 참여한 가운데 관련 기계기술 연구 현황과 해결 방안을 논의하기 위하여 마련되었습니다.

미세먼지는 단순 호흡기 질환 뿐 아니라 두통과 현기증, 피부병, 눈병, 혈관질환, 뇌질환 등 우리의 건강에 막대한 영향을 미칠 수 있는 대단히 위험하고도 심각한 문제입니다. 인간 뿐 아니라 동식물에도 악영향을 일으켜 생태계마저도 위협받고 있는 상황입니다.

이러한 동북아 미세먼지 문제는 우리만의 의지와 노력만으로는 해결이 불가합니다. 동북아 3국이 머리를 맞대고 같이 노력해야만 해결할 수 있으며, 이에 오늘 행사는 그 어느 때보다 의미가 크다고 할 수 있습니다.

오늘 이루어질 동북아 3국의 전문가들의 논의를 바탕으로 다양한 기술이 미세먼지 발생과 관리에 적용되어 국민의 안전한 생활환경을 만들도록 지원하고, 정부와 국회가 미세먼지 문제 해결을 위해 적극적으로 정책을 수립하고 예산을 지원할 수 있도록 최선을 다하겠습니다.

이번 행사를 주최한 한국기계연구원이 첨단 기계기술을 활용하여 미세먼지 문제 해결에 그 역할을 다 하시리라 굳게 믿습니다.

바쁘신 와중에도, 미세먼지 해결에 관심을 갖고 참석해주신 모든 분들께 다시 한 번 감사드립니다.

인 사 말 씀

자유한국당

자유한국당 정책위의장

정 용 기

여러분, 반갑습니다. 자유한국당 정책위의장 정용기입니다.

먼저 바쁘신 일정 중에도 미세먼지 문제를 진단하고 정책 대안을 제시하는 포럼에 참석하신 모든 분들께 감사의 말씀을 드립니다. 또한, 발제를 맡아주신 국내 · 외 전문가 여러분들께도 깊이 감사드립니다.

올해 초부터 우리 국민의 생명과 안전을 위협하는 '미세먼지'가 극성을 부리면서 수많은 국민들이 고통의 나날을 보내야 했습니다. 오늘 포럼의 주제를 '미세먼지'로 잡은 것도 바로 이런 이유 때문입니다.

지난 3월 국회는 미세먼지 발생을 낮추고 다중이용시설의 대기질 개선과 관리 강화를 위한 법안들을 다수 통과시킨 바 있습니다. 하지만 아직도 가야할 길이 멉니다. 미세먼지 문제 해결을 위한 재정적 뒷받침을 위하여, 추경을 통해 국민들이 조금이라도 안심할 수 있도록 노력했습니다.

그러나 이러한 조치를 넘어 근본적인 정책의 전환이 요구됩니다. '친환경 에너지원'인 원전은 줄이고 대신 '미세먼지 배출 주범'인 석탄 발전을 늘리는 등 '거꾸로' 정책을 펴왔습니다. '탈원전 정책 폐기'와 '중국과의 협력' 강화라는 명확한 해답이 이미 나와 있는데도, 이 정권은 반대로 탈원전 정책을 밀어붙이고 중국에는 입도 뻥긋 못하고 있습니다.

미세먼지 문제는 어느 한 나라만의 문제가 아닙니다. 중국과 일본 등 서로 인접한 국가들이 영향을 주고받을 수밖에 없습니다. 오늘 중국과 일본, 독일 등 세계 각국의 미세먼지 분야의 내로라하는 전문가들이 모이신 만큼, 올바른 정책방향을 제시해주시기 바랍니다. 오늘 주신 고견은 깊이 새기고, 우리나라 미세먼지 문제 해결을 위해 최대한 반영해나가겠습니다.

오늘 토론회 주최자로서 이 자리를 빛내주신 내외귀빈들께 다시 한 번 감사의 말씀을 드리며, 포럼에 함께 해주신 모든 분들의 건강과 행복을 기원합니다.

감사합니다.

프로그램

13:00–13:20	등록 및 접수
13:20–13:50	개회사 및 축사
13:50–15:05	세션 1 : 동북아와 미세먼지
	>> 한국기계연구원 송영훈 환경시스템연구본부장 해외 대기오염 저감사례 및 우리나라 미세먼지 해결방법
	>> 중국 절강대(Zhejiang University) Keping Yan 교수 전기집진기술의 현재와 미래
	>> 일본 도요하시 기술과학대(Toyohashi University of Technology) Akira Mizuno 명예교수 (前 일본 정전기학회장) 일본의 산업공해 관리
15:05–15:20	휴식
15:20–16:35	세션 2 : 미세먼지 저감 기계기술
	>> 독일 칼스루헤 공과대(KIT) Thomas Koch 교수 배출가스 저감과 내연 기관의 미래
	>> 두산중공업 송시홍 전략/혁신부문Plant기술개발센터장 석탄화력발전 미세먼지 저감 기술
	>> 한국기계연구원 한방우 환경기계연구실장 한국기계연구원 미세먼지 저감 연구개발 현황 및 발전방향
16:35–16:50	질의응답/폐회

PROGRAM

13:00–13:20	**Registration**
13:20–13:50	**Opening Remarks / Congratulatory Remarks**
13:50–15:05	**Session 1: Northeast Asia & Fine Particles**
	>> Young Hoon Song / Director, KIMM / Korea **Overseas Case Studies of Air Pollution Reduction and Combating Fine Particles in Korea** >> Keping Yan / Professor, Zhejiang University / China **Electrostatic Precipitation: Present and Future** >> Akira Mizuno / Professor Emeritus, Toyohashi University of Technology / Japan **Control of Industrial Air Pollution in Japan**
15:05–15:20	**Break**
15:20–16:35	**Session 2: Mechanical Engineering for Reducing Fine particles**
	>> Thomas Koch / Professor, Karlsruhe Institute of Technology Germany **Emissions and Immissions - The Diesel Perspective** **An Assessment of the Future of Internal Combustion Engines** >> Si Hong Song / Vice President, Doosan Heavy Industries & Construction / Korea **Emission of Fine Dust From Coal-Fired Power Plants, and Doosan's Fine Dust Reduction Technology** >> Bang Woo Han / Dept. Head, KIMM / Korea **KIMM's Research Status on Fine Particle Reduction and Development Plans**
16:35–16:50	**Q&A / Closing**

연사 소개 및 발표 요약

송 영 훈

한국기계연구원 환경시스템연구본부장

2014~현재 한국연소학회 감사, 부회장
2011~현재 한 · 일 · 중 플라즈마 정전기교류회 조직위원장
1994~현재 한국기계연구원 책임연구원(환경시스템연구본부장)
1989~1994 미국 펜실베니아주립대 박사(기계공학)
1984~1986 한국과학기술원 석사(기계공학)
1978~1983 한양대 학사(기계공학)

해외 대기오염 저감사례 및 우리나라 미세먼지 해결방법

대기오염 문제는 화석연료를 기반으로 하는 경제활동에서 반드시 발생하는 문제이다. 따라서 지난 20세기 여러 선진국 도시들은 산업화를 이루면서 다양한 종류의 대기오염 문제를 겪어왔다. 그러나 이들 선진국들은 적절한 대기오염 기술의 활용과 정책을 통해 대기오염 문제를 해결해왔고, 오늘날 이들 국가들에서 대기오염은 더 이상 사회적 이슈가 아니다.

본 발표에서는 런던, LA, 도쿄 등 대기오염 문제를 극복해온 도시를 중심으로 1)당시의 대기오염 상황과 원인, 2)저감기술, 3)정책을 살펴본다. 본 발표의 후반부에서는 우리나라가 갖고 있는 대기오염을 결정하는 여러 조건들, 즉, 지리, 기후, 산업 및 에너지 공급원 구조(에너지 믹스) 등이 다른 선진국들과는 다름에도 불구하고, 우리나라에서도 과거 선진국들이 적용해왔던 대기오염 기술과 정책이 얼마나 효과가 있는지 전망해본다.

Young Hoon Song

Director
Environment System Research Division
Korea Institute of Machinery and Materials(KIMM)
Korea

2014∼Present	Vice President · Auditor/The Korean Society of Combustion
2011∼Present	President/Korea · Japan · China Electro–Plasma Forum
1994∼Present	Researcher/KIMM
1989∼1994	Ph.D./Pennsylvania State University(ME)
1984∼1986	M.S./KAIST(ME)
1978∼1983	B.S./Hanyang University(ME)

Overseas Case Studies of Air Pollution Reduction and Combating Fine Particles in Korea

Air pollution is an inevitable problem that arises with economic activities involving the consumption of fossil fuels. In the 20th century, many advanced countries experienced various air pollution issues in the process of industrialization. However, they have overcome such problems through effective implementation of technology and policies. As a result, air pollution is no longer a social issue in advanced countries today.

This presentation examines 1)the circumstances and causes of air pollution, 2)reduction technology, and 3)policies, with a focus on London, LA, and Tokyo. The second half of this presentation reviews whether the technology and policies implemented by advanced countries in the past can take effect in Korea, despite differences in geography, climate, and sources of industrial and energy supply(energy mix).

연사 소개 및 발표 요약

커핑 옌

중국 절강대학교 산업생태환경연구소 교수

2008~2011	국제전기집진학회(ISESP) 이사회장
2006~현재	중국 절강대학교 교수
2004	종허 환경기술 주식회사 공동 설립
2001	네덜란드 아인트호벤 공과대학 박사(전기공학)
1983~1986	중국 북경 이공대학 학사 · 석사(응용물리학)

전기집진 기술의 현재와 미래

산업용 전기집진기(ESP)는 다양한 업계에서 사용되고 있다. 본 발표는 미세먼지 및 다중오염 배출저감을 위해 우리 연구팀이 현재 연구 중인 1)고온 전기집진기(high–temperature ESP), 2)저온 전기집진기(cold–side ESP), 3)저저온 전기집진기(colder–side ESP) 및 4)습식 전기지진기(wet ESP) 등에 초점을 맞추었다. 앞으로 "ESP Index 모델"을 적용함으로서 1,100MW 이하 석탄보일러에 5mg/m^3이하 수준 전기집진기 보급이 가능해질 것이며, 추후 미세먼지(PM 2.5) 농도가 2.5mg/m^3 수준으로 관리가 가능해질 것으로 기대된다. 또한 차세대 전기집진기술은 고압전원장치 업그레이드를 통해 스트리머 코로나 플라즈마 방전을 그 기반으로 하게 되었다. 이러한 기술들은 집진뿐만 아니라 배연가스 산화 처리에도 사용될 수 있으며, 그간 산업계 기술 시범을 통해 운영 및 투자비용에서 우수함이 확인됐다.

Keping yan

Professor
Institute of Industrial Ecology and Environment
College of Chemical and Biological Engineering
Zhejiang University
China

2008~2011	President/International Society for Electrostatic Precipitation(ISESP)
2006~Present	Professor/Zhejiang University
2004	Co-founder/Zhonghe Environmental Technology Inc.
2001	Ph.D./Eindhoven University of Technology(EE)
1983~1986	B.S., M.S./Beijing Institute of Technology

Electrostatic Precipitation: Present and Future

Industrial Electrostatic Precipitators(ESPs) have been widely used in various industries. This presentation will focus on our present works on 1)high-temperature ESP, 2)cold-side ESP, 3)colder side ESP and 4)wet ESP for fine particle and multi-pollutants emission control. By using the so-called "ESP index model", less than 5 mg/m^3 emission-level ESPs will become popular for up to 1100MW coal-fired boilers, in which PM2.5 can become less than 2.5 mg/m^3. By upgrading high-voltage power sources, next generation ESPs are based on streamer corona plasma discharge. They can be used for not only collecting particle matters but also for oxidizing flue gases. Industrial demonstrations have confirmed its advantages for both operation and investment costs.

연사 소개 및 발표 요약

아키라 미즈노

일본 도요하시 기술과학대학교 명예교수
前 일본 정전기학회장

2005~현재	전기전자학회(IEEE) 회원/종신회원
2013~2017	일본 정전기학회장
2016~현재	일본 도요하시 기술과학대학교 명예교수
2005~2016	일본 도요하시 기술과학대학교 교수
2003~2004	일본 오카자키 국립연구소 연구원
1981~2003	일본 도요하시 기술과학대학교 교수
1978~1981	IHI 중공업 연구원
1978	일본 도쿄대학교 박사(전기공학)

일본의 산업공해 관리

일본은 메이지유신 이후 현대산업화가 시작됐으며, 여러 부문의 중공업이 발전함에 따라 환경오염 문제도 함께 발생하였다. 일본 최초의 대기오염 문제는 1880년대 아시오(Ashio) 구리 광산에 의해 발생한 것으로, 폐수로 인해 강이 오염되고, 잇따라 황산과 먼지가 발생하여 심각한 대기오염으로 발전했다. 전기집진 기술은 대기오염 해결을 위해 일본으로 1916년 처음 도입 되었으며, 1920년대 들어 먼지입자의 대전(charging) 및 집진(collection)에 대한 연구가 시작되었다. 전쟁 이후 중공업이 부흥하기 시작함에 따라 1950년대에는 "욧카이치 천식사건" 등 심각한 공해가 발생했다. 이러한 공해 발생 이후 여러 규제들이 제정되었으나, 1970년대 사용 에너지원 교체로 인해 새로운 기술적 문제들이 대두되었다. 전기집진기술의 경우 역코로나 문제가 발생하여 집진 기능이 거의 무효화되기도 하였다. 이러한 기술적 문제들은 집중적인 연구개발을 통해 해결되었고, 그 해결 과정에서 미세먼지 측량기술 및 디젤엔진 배출필터 등 가스성 오염물질 관리를 위한 비열 플라즈마(NTP) 기술이 개발되었다. 우리는 이와 같은 기술들을 활용하여 우리의 건강과 환경을 지킬 수 있을 것이다.

Akira Mizuno

Professor Emeritus
Toyohashi University of Technology
Japan

2005～Present	Fellow · Life Fellow/Institute of Electrical and Electronics Engineers(IEEE)
2013～2017	President/Institute of Electrostatics Japan
2016～Present	Professor Emeritus/Toyohashi University of Technology
2005～2016	Professor/Toyohashi University of Technology
2003～2004	Researcher/Okazaki National Research Institute
1981～2003	Professor/Toyohashi University of Technology
1978～1981	Researcher/IHI heavy industries Co., Ltd.,
1978	Ph.D./University of Tokyo(EE)

Control of Industrial Air Pollution in Japan

In Japan, modern industrialization has begun after Meiji revolution, and various heavy industries have been developed. First pollution reported was caused by Ashio copper mining located near Nikko in 1880's. River was polluted by the waste water, then developed air pollution due to particles and sulfuric acid. Electrostatic precipitators, invented in 1907 in USA, was imported in 1916 and installed and studies were made on particle charging and collection in 1920's. After the war, heavy industries started to develop again and in 1950's, severe pollution also started, such as Yokkaichi air pollution due to oil refinery. Regulations followed after the development of these pollutions, but in 1970's, difficult technical problem emerged along with the switch of energy source from oil to coal. Electrostatic precipitators had back corona problem and their function almost stopped. This problem has been solved eventually by intensive research and development. From these research activities, non–thermal plasma technology, NTP, has been developed for control of gaseous pollutants. The technique to measure charge and size of fine particles enables us to cope with nano–particles. Filters also contributed to reduce PM, especially from diesel engines. These technologies will contribute to maintain/improve our health.

연사 소개 및 발표 요약

토마스 코흐

독일 칼스루헤 공과대학교 교수
칼스루헤 공과대 자동차동력기관연구소장

2013~현재 독일 칼스루헤 공과대 자동차동력기관연구소장
2012~현재 독일 칼스루헤 공과대 교수
2003~2013 다임러(Daimler) 연구원
2002 스위스 취리히 연방 공과대학교 박사(기계공학)

배출가스 저감과 내연기관의 미래

연소엔진의 미래에 대한 논의는 지금도 활발하게 진행되고 있다. 미세먼지 및 이산화질소 배출량의 증가로 인하여, 내연기관의 미래에 대한 관련 논의가 심화되고 있으며, 영국이나 프랑스 같은 국가들은 배출량 저감을 위해 심지어 내연기관기술 사용 금지까지 신중하게 고려하고 있다. 하지만 전체 배출량 중 내연기관으로 인한 배출량이 어느 정도인지는 명확하지 않으며, 또 내연기관의 발전 가능성이나, 기존기술의 배출량 저감 가능성, 배출량 저감을 위해 어떤 기술이 적용되어야 하는지 등의 여러가지 질문들이 남아 있다. 다시 말해, 내연기관이 정말 우리에게 필요한지, 내연기관의 미래가 어떻게 발전할 것인지 등도 고려해야 한다. 매연 및 미세먼지가 실제로 어떻게 영향을 미치는지, 디젤 및 가솔린 엔진의 배출가스 구분이 따로 필요한지 등에 대한 논의도 필요하다. 특히 배출저감을 위해 최근 유럽연합에서 시행 중인 실주행 조건 배출가스 규제(Real Driving Emission)와 이동형 배출가스 측정장치(PEMS)에 대해서도 추가적으로 논의하고자 한다.

Thomas Koch

Professor/Director
Internal Combustion Engine Research Institute(IFKM)
Karlsruhe Institute of Technology
Germany

2013∼Present	Director, Karlsruhe Institute of Technology IFKM
2012∼Present	Professor, Karlsruhe Institute of Technology
2003∼2013	Researcher/Daimler
2002	Ph.D./Swiss Federal Institute of Technology(ETH Zürich, ME)

Emissions and Immissions – The Diesel Perspective An Assessment of the Future of Internal Combustion Engines

Intensive discussions about the future of the combustion engine are currently ongoing. The exceeding of PM as well as NO_2–immission values for many years has intensified the discussions, how there might be a future of the internal combustion engine. Additionally, countries like Great Britain or France very intensively evaluate the possibility to forbid the combustion engine technology. But which is the contribution of internal combustion engines to particulates as well as gaseous emissions. How is the real immission situation? How is the potential of yesterdays, todays and future's combustion engine? Is there a chance to further reduce the current immission values? Which technologies must be applied in order to solve the situation? Basically the major question is of interest, whether there is a future for the combustion engine or not? How is the impact of soot, particulate emissions? Is there a need to distinguish between diesel and gasoline engines? These questions will be part of the discussion. Especially the important impact of the legislation on the emissions situation has to be evaluated as well. Therefore, the new Real Driving Emission legislation and the influence of portable emission measurement devices(PEMS) will be discussed additionally.

연사 소개 및 발표 요약

송 시 홍

두산중공업
전략/혁신부문Plant기술개발센터장(상무)

2015~현재 두산중공업 기술연구원 상무
2000~2015 두산중공업 기술연구원 연구원
1987~2000 삼성중공업 연구원
1996 한국과학기술원 박사
1987 한국과학기술원 석사

석탄화력발전 미세먼지 저감 기술

두산중공업은 석탄화력, 원자력 발전소 및 담수설비를 건설하여 공급하는 에너지와 Water 분야의 대한민국 대표 기업이다. 최근 미세먼지 이슈가 화두로 부각되면서, 석탄화력발전소가 주요 배출원으로 지목되어 배출물 저감을 위한 환경설비의 개조 및 강화가 주목 받고 있다. 석탄화력 발전소의 1차 오염원인 먼지와 2차 오염원으로 미세먼지의 성장에 기여하는 NOx, SOx의 배출저감 방법으로는 발전 플랜트의 효율 증대, Low NOx 버너 등 연소방식의 변경, 혁신적 후처리 기술 적용, 또는 IGCC와 같은 새로운 석탄활용기술을 이용한 배출저감 등이 있다. 두산중공업은 다양한 기술을 보유하고 제공해 왔으며, 지속적으로 환경설비(SCR, FGD, ESP), Low NOx버너 등의 성능 개선 연구를 수행하여 보다 좋은 제품을 공급하고자 노력하고 있다. 본 발표에서는 석탄화력 발전소에서 배출하고 있는 미세먼지 현황에 대해 살펴보고, 미세먼지의 혁신적 감축을 위한 두산중공업의 연소, 플랜트 설계, 환경설비에 대해 설명하고 본 기술들을 적용하였을 때의 미세먼지 저감 효과에 대해 논의하고자 한다.

Si Hong Song

Vice President
Plant Technology Development Center / Strategy & Innovation Division
Doosan Heavy Industries & Construction Co., Ltd
Korea

2015∼Present	Vice President/Doosan Heavy Industries & Construction Co., Ltd
2000∼2015	Researcher/Doosan Heavy Industries & Construction Co., Ltd
1987∼2000	Researcher/Samsung Heavy Industries
1996	Ph.D. / KAIST
1987	M.S. / KAIST

Emission of Fine Dust From Coal–Fired Power Plants, and Doosan's Fine Dust Reduction Technology

As a leading Korean company in Energy, Power, and Water business, Doosan Heavy Industries & Construction have been constructed and supplied coal–fired power plants, nuclear power plants, and desalination plants in the world. The emergence of fine dust as a pressing issue has highlighted the need to retrofit the air pollution control system of coal–fired power plants which is identified as one of the biggest contributors of fine dust emission. Some methods of reducing fine dust, NOx and SOx, which contribute to primary dust and secondary contribution to fine dust, from coal–fired power plants include increasing the efficiency of power plants, upgrade the combustion burner to low NOx burners, applying innovative post–processing technology, and employing IGCC or other new techniques of coal utilization. Doosan Heavy Industries & Construction has an extensive technology portfolio, and actively conducts research to improve the performance of its air pollution control devices (SCR, FGD, ESP) and low NOx burners. This presentation reviews the levels of fine dust emitted by coal–fired power plants, and introduces Doosan Heavy Industries & Construction's combustion technology, plant design, and air pollution control technologies. The amount of reduction of fine dust emission can be achieved by which Doosan's newly developed innovative air pollution technology is applied, will also be discussed.

연사 소개 및 발표 요약

한 방 우

한국기계연구원 환경기계연구실장

2016～현재 한국입자에어로졸학회 편집위원장
2003～현재 한국기계연구원 책임연구원(환경기계연구실장)
1999～2003 서울대학교 박사(기계공학)
1997～1999 서울대학교 석사(기계공학)
1993～1997 서울대학교 학사(기계공학)

한국기계연구원 미세먼지 저감 연구개발 현황 및 발전방향

미세먼지는 대부분 인류가 연소라는 과정에서 배출하는 오염물질이다. 따라서 연소 과정에서 배출되는 오염원을 관리하는 것이 매우 중요하다. 한국기계연구원은 그동안 미세먼지 주요 배출원인 산업공정이나 디젤엔진에서 배출되는 1차 미세먼지와 관련 2차 생성물질을 저감시키기 위한 다양한 배기정화기술 연구를 수행해왔다. 본 발표에서는 기계연에서 그동안 다양한 산업분야의 미세먼지 저감을 위해 진행해왔던 정전응집 및 건습식 전기집진기 개발, SOx, NOx와 같은 2차 생성물질 처리를 위한 고체환원제 촉매장치나 산화 · 환원 스크러버 개발 등을 소개하고자 한다. 또한 미세먼지는 그동안 배출 관점에서 접근되었으나 앞으로 노출관점에서 많은 시간을 생활하는 실내공간에서의 관리방법이 매우 중요하다. 기계연이 진행해왔던 실내 공간에서 미세먼지의 노출 저감을 위한 새로운 공기청정기의 개발이나 생활공간에서의 미세먼지 관리 기술에 대해서도 소개하고 향후 미세먼지 저감과 관련된 기계연의 기술개발 계획에 대해 간략하게 언급하고자 한다.

Bang Woo Han

Head
Department of Environmental Machinery
Korea Institute of Machinery and Materials(KIMM)
Korea

2016∼Present	Editor in Chief/Korean Association for Particle & Aerosol Research
2003∼Present	Researcher/KIMM
1999∼2003	Ph.D./Seoul National University(ME)
1997∼1999	M.S./Seoul National University(ME)
1993∼1997	B.S./Seoul National University(ME)

KIMM's Research Status on Fine Particle Reduction and Development Plans

Fine particles are mostly emitted by man–made combustion processes. Therefore, it is very important to manage the pollution sources during combustion. The Korea Institute of Machinery & Materials(KIMM) has conducted researches on various exhaust purification techniques to reduce primary fine particles and secondary gaseous substances released from industrial processes and diesel engines. This presentation introduces the institute's development of dry/wet electrostatic precipitators for fine particle reduction in various industries, and the development of solid selective catalytic reduction devices and oxidation/reduction scrubbers for the treatment of secondary products such as SOx and NOx. While many studies have approached fine particles emitted from exhausts or stacks, it becomes important to manage human exposure of fine particles in indoor environments. KIMM's newly developed indoor air purifiers and fine particle management techniques are also introduced, followed by a brief overview of KIMM's research plans for fine particle reduction.

SESSION III

동북아와 미세먼지

Northeast Asia & Fine Particles

SESSION 1

동북아와 미세먼지

해외 대기오염 저감사례 및 우리나라 미세먼지 해결방법

Overseas Case Studies of Air Pollution Reduction and Combating Fine Particles in Korea

>> 한국기계연구원 송영훈 환경시스템연구본부장

Young Hoon Song / Director, KIMM / Korea

해외 대기오염 저감사례 및 우리나라 미세먼지 해결방법

한국기계연구원

송 영 훈 환경시스템연구본부장

KIMM 한국기계연구원

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해외 대기오염 저감사례 및
우리나라 미세먼지 해결방법

01 _ 미세먼지 정의 및 발생

02 _ 중국의 영향, 어떤 것인가?

03 _ 해외사례 및 저감기술

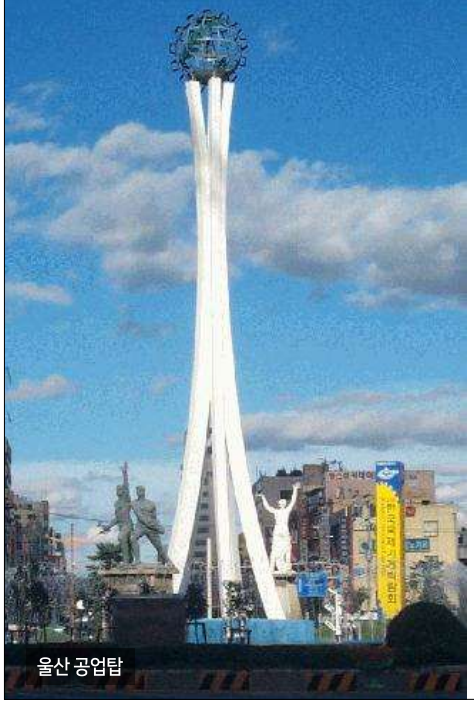
04 _ 우리는 어떻게 대처할 것인가?

해외 대기오염 저감사례 및
우리나라 미세먼지 해결방법

01_ 미세먼지 발생의 원인

01 미세먼지 발생의 원인

미세먼지의 발생



울산 공업탑

울산도약 선언문

4천년 빈곤의 역사를 씻고 민족 숙원의 부귀를
마련하기 위하여 우리는 이곳 울산을 찾아
여기를 신(新)공업도시로 건설하기로 했습니다.
……(중략)……
산업 생산의 검은 연기가 대기 속에 뻗어나가는
그날엔 국가 민족의 희망과 발전이 이에 도래하였음을
알 수 있을 것입니다.
빈곤에 허덕이는 겨레 여러분…… (이하 생략)
---- 1967 년 ----

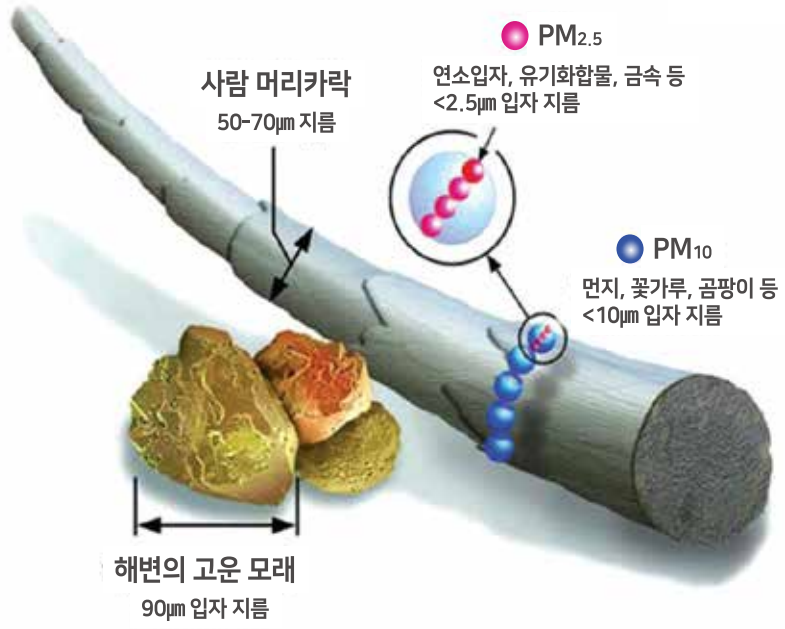
미세먼지는 산업화의 부산물

4

01 미세먼지 발생의 원인

미세먼지의 발생

※ 1㎛ = 1/1000mm



*출처:환경부e-book

5

01 미세먼지 발생의 원인

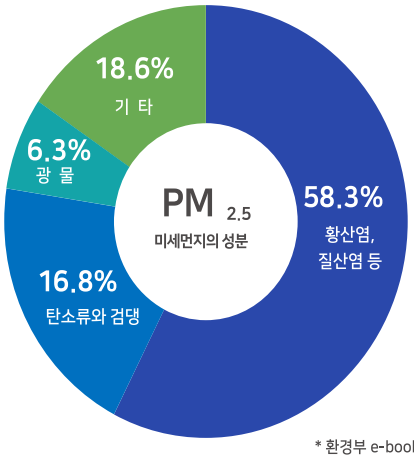
미세먼지의 발생

과 거

☑ 대기오염
- 아황산가스 (SOx)
- 질소산화물 (NOx)
- 미연탄화수소 (Hydrocarbon)
- 일산화탄소 (CO)
- 분진
- 오존 (O3)
- 휘발성 유기화합물
- 중금속

현 재

☑ 미세먼지
- PM10
- PM2.5

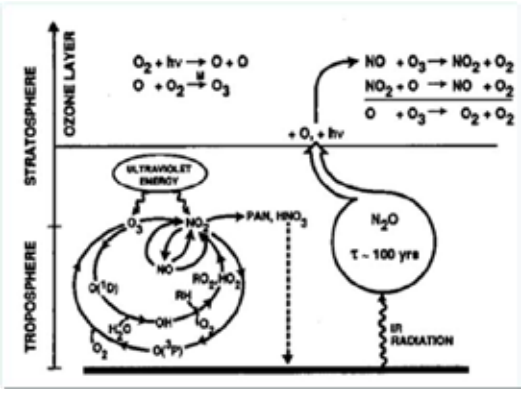


* 환경부 e-book

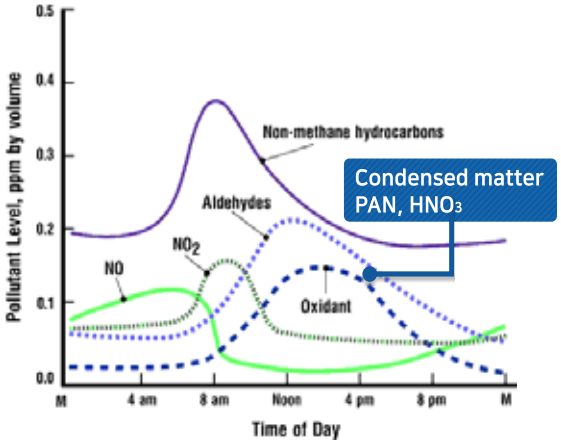
6

미세먼지의 발생

연소 배기가스에서 배출된 질소산화물의 일생



24th symposium (international) on Combustion, 1992/pp. 859-878



PAN : Peroxyacyl nitrates, toxic & irritating

공기 ($N_2 + O_2$) + 고온 연소 → NO, NO_2 (질소산화물)

01 미세먼지 발생의 원인

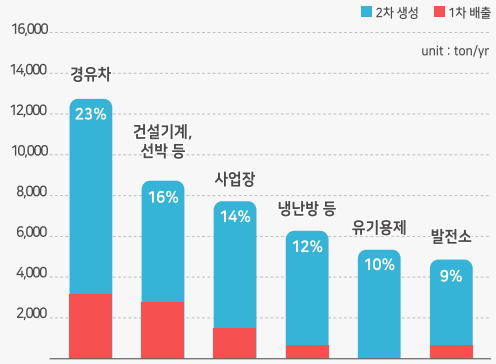
미세먼지의 발생

01 미세먼지 발생의 원인

미세먼지의 발생

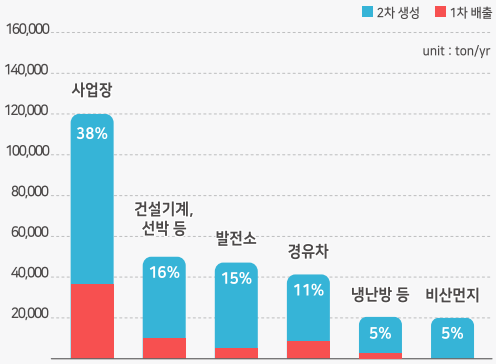
미세먼지의 발생 요인

수도권



수도권 기타 배출원 : 비산먼지 8%, 생물성연소 4%, 휘발유차등 4%

전 국



전국 기타 배출원 : 생물성연소 5%, 유기용제 사용 4%, 휘발유차등 1%

* 관계부처 합동 미세먼지 관리대책 발표자료 2017.09.26

01 미세먼지 발생의 원인

미세먼지의 발생

미세먼지 발생의 국내·외 요인

(국외영향)국외영향의 비율은 계절, 기상조건에 따라 상이

- **(정부) 평상**시 중국, 북한 등을 포함한 **국외 영향은 연평균 30~50%, 고농도시** ('15~'16년 연간 18~29일)**에는 60 ~ 80%로 추정**
- 美 항공우주국(NASA)과의 공동연구 결과('17.7월, 중간 발표)도 중국 등 **국외영향 48%, 국내배출 52%로 분석**(측정시점 : '16.5~6월)

미세먼지 관리종합대책(관계부처합동) 2017.09.26

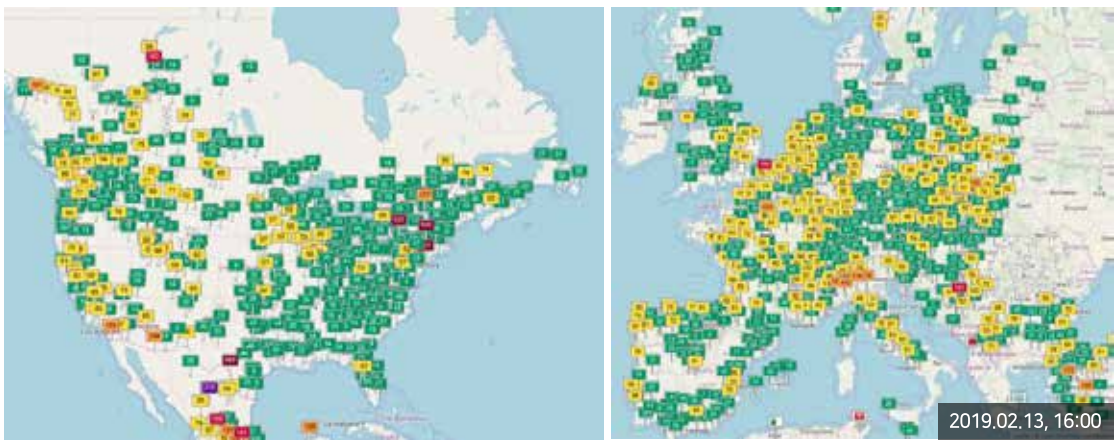
문제점

- **우리나라에서 할 수 있는 저감대책은 없는가?**
- **최근 중국은 미세먼지가 줄고 있는데?**

해외 대기오염 저감사례 및
우리나라 미세먼지 해결방법

02_ 중국의 영향, 어떤 것인가?

Air quality in North America & Europe(aqicn.org)



Air Pollution Level

0-50	51-100	101-150	151-200	201-300	300+
Good	Moderate	Unhealthy For Sensitive Groups	Unhealthy	Very Unhealthy	Hazardous

02 중국의 영향, 어떤 것인가?

Air quality in Asia

Air Pollution Level

0-50	51-100	101-150	151-200	201-300	300+
Good	Moderate	Unhealthy For Sensitive Groups	Unhealthy	Very Unhealthy	Hazardous

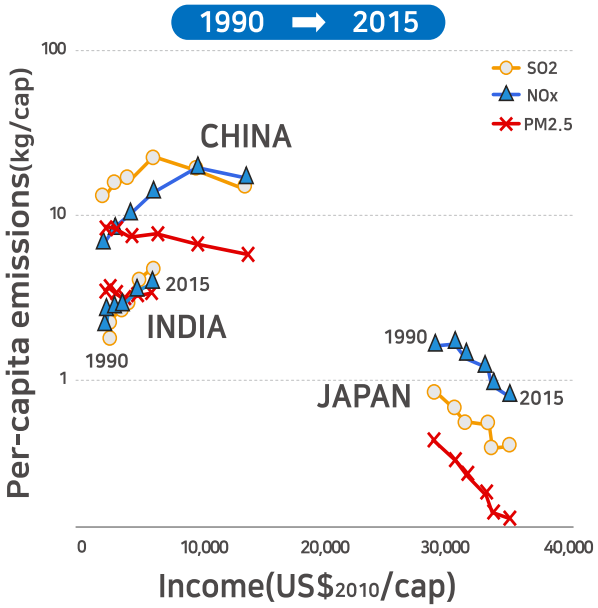
02 중국의 영향, 어떤 것인가?

2019.06.11, 15:15 대기질

중국의 영향은 크지만 그 영향력은 기후에 따라 크게 좌우된다

02 중국의 영향, 어떤 것인가?

중국, 인도, 일본에서의 미세먼지 배출 변화



* Energies 2018, 11, 1299

중국발 미세먼지 발생량은 줄어드는 추세

02 중국의 영향, 어떤 것인가?

중국의 영향

중국의 미세먼지 발생량은
최근 급격하게
줄어들고 있는 추세

중국의 영향을 받고 있으나,
기후에 따라 크게 다르다
(봄, 겨울 고농도 미세먼지, 삼한사미)

국내발 미세먼지를
줄이는 것이 가장
빠르고 효과적이 대책

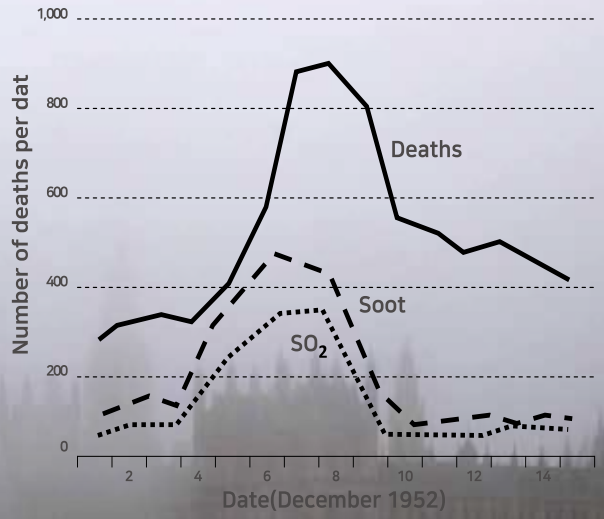
16

02 중국의 영향, 어떤 것인가?
대기오염 발생과 저감
제조업
(제철, 화학 등)
건설기계
선박
자동차
발 전
냉 난방
발 생
저 감
에너지
효율향상
배기정화
(집진, 탈황, 탈질 등)
청정연료
전환
에너지 다소비 산업
에너지 저소비 산업

해외 대기오염 저감사례 및
우리나라 미세먼지 해결방법
03_ 해외사례 및
저감기술

03 해외사례 및 저감기술

Great smog in London, 1952

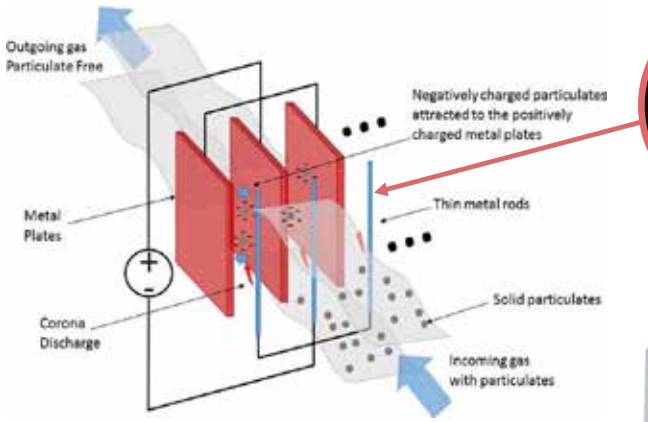


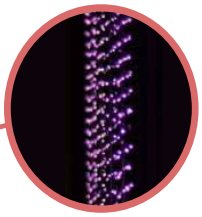
J.Fenger/Atmospheric Environment 43(2009) 13–22

03 해외사례 및 저감기술

저감기술

전기 집진기





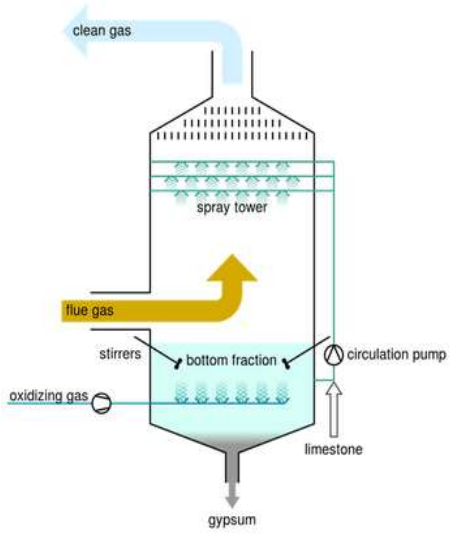
Electrical discharge
Onset voltage : 30 kV/cm

[개발시기 : 19세기 후반]

20

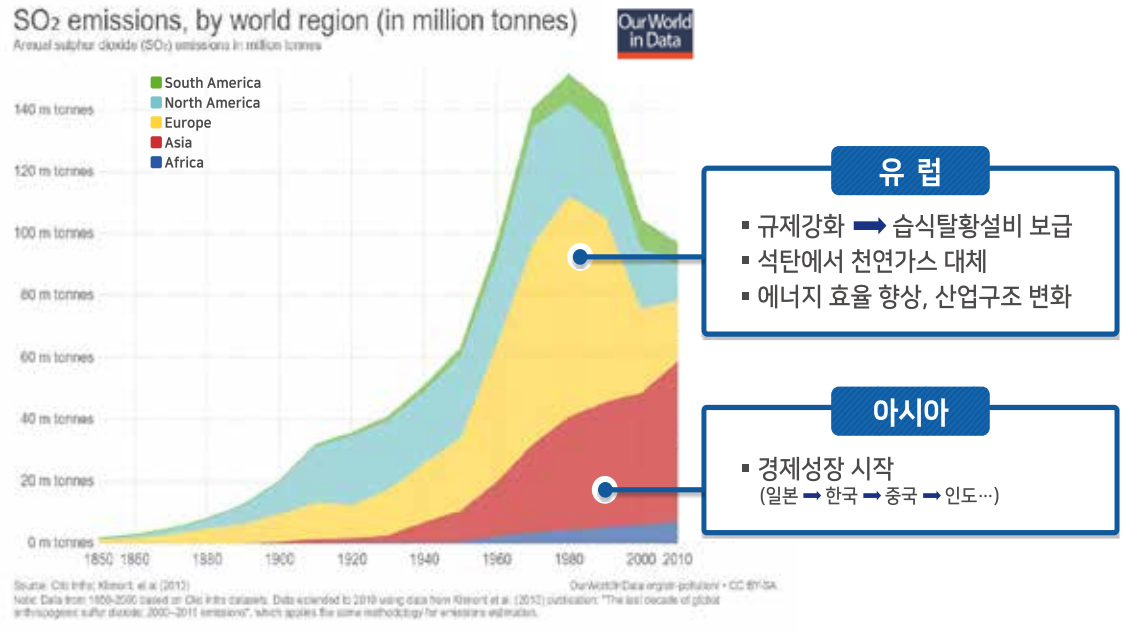
저감기술

Wet scrubber(습식 탈황설비)



보령화력 1호기 탈황설비

대륙별 SO_2 배출량



유 럽

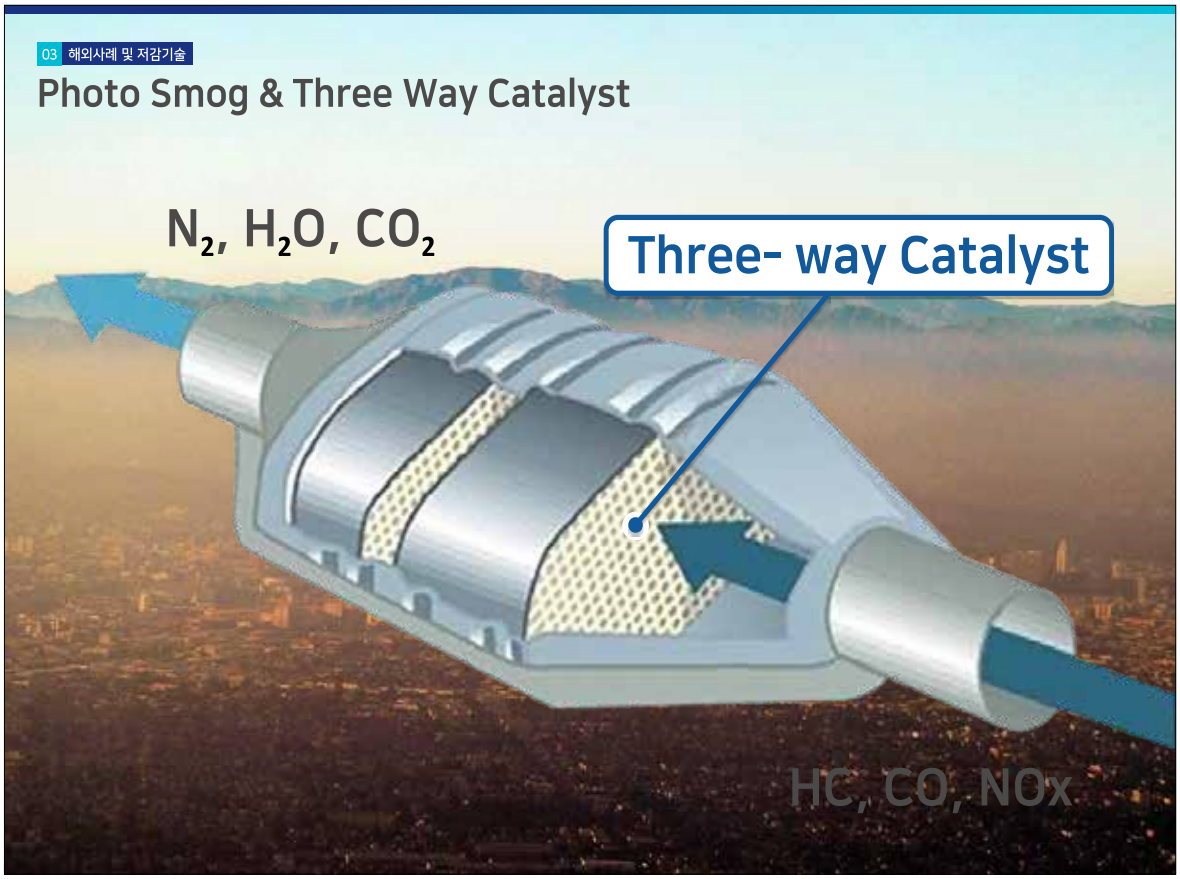
- 규제강화 ➡ 습식탈황설비 보급
- 석탄에서 천연가스 대체
- 에너지 효율 향상, 산업구조 변화

아시아

- 경제성장 시작
  (일본 ➡ 한국 ➡ 중국 ➡ 인도…)

03 해외사례 및 저감기술

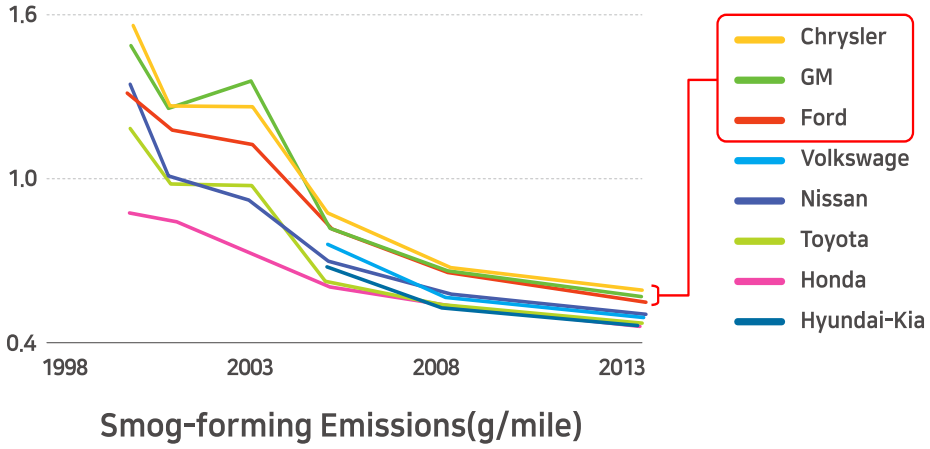
Photo Smog & Three Way Catalyst



03 해외사례 및 저감기술

상위 8대 자동차 제조기업 LDV 평균 배출량

Average Emissions from Light-Duty Vehicles
Sold by the Top Eight Automakers, 1998-2013

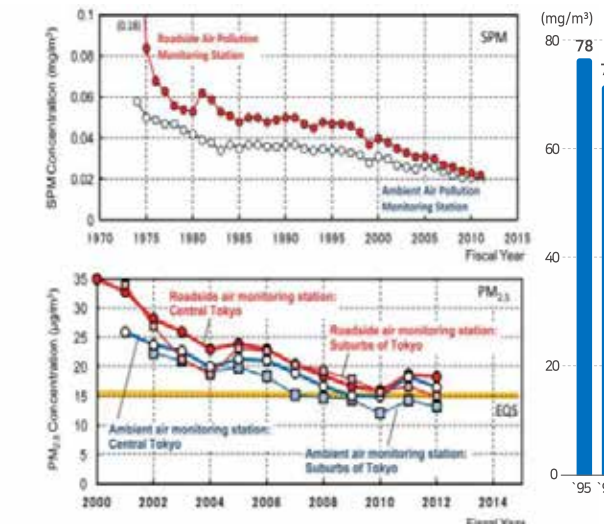


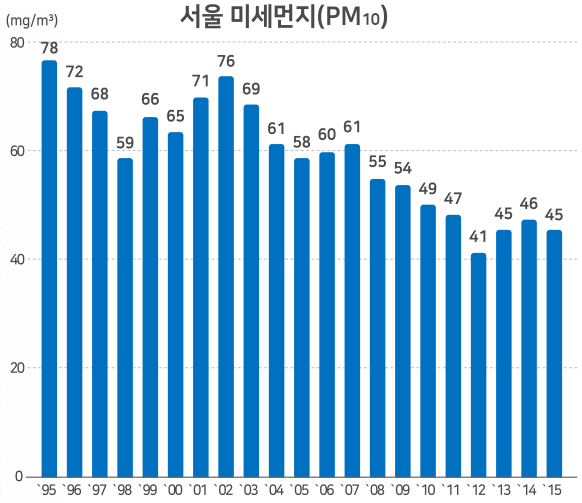
Smog-forming Emissions(g/mile)

© Union of Concerned Scientist ; www.ucsusa.org/2014autorankings

24

일본의 대기오염 극복사례





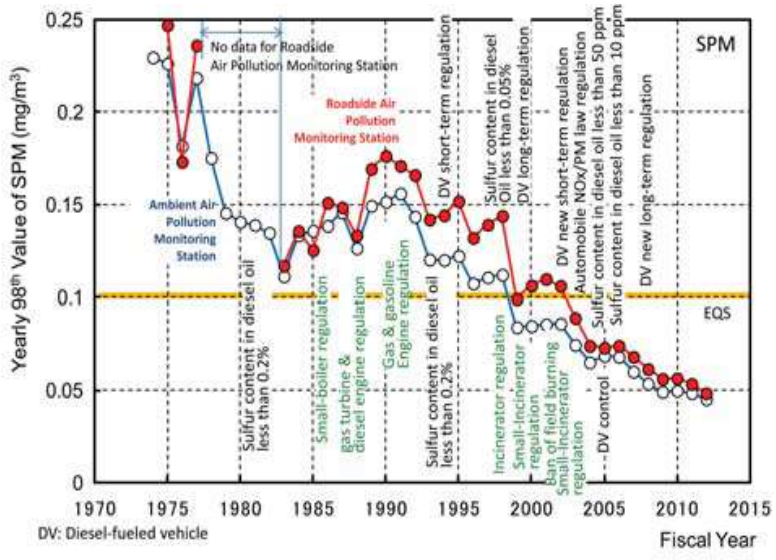
Asian Journal of Atmospheric Environment
Vol. 7-4, pp.177-190, December 2013

중국발 미세먼지 발생량은 줄어드는 추세

03 해외사례 및 저감기술

일본의 대기오염 극복사례

Asian Journal of Atmospheric Environment
Vol. 7-4, pp.177-190, December 2013



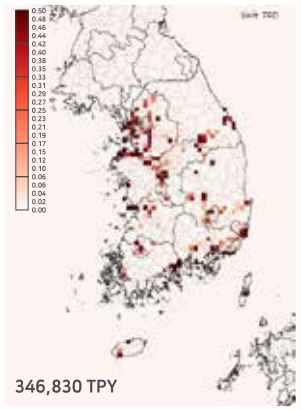
자동차 배기규제와 미세먼지 농도감소 동조화(synchronized)현상

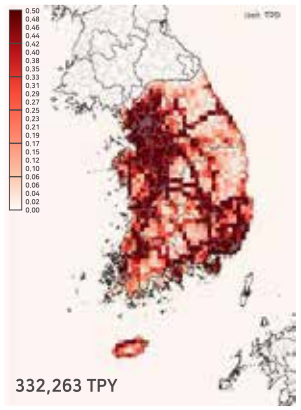
03 해외사례 및 저감기술

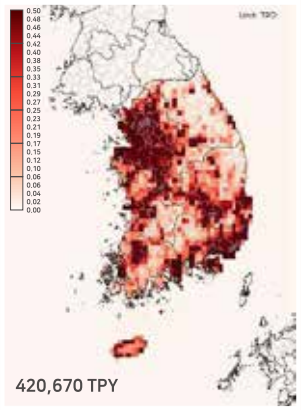
점 – 선 – 면 오염원

전국 Nox 배출량

한국환경정책·평가연구원 문난경 박사







점 오염원	선 오염원	면 오염원
발전소, 대규모 사업장	자동차	소규모 사업장(주유소, 세탁소 등)

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해외 대기오염 저감사례 및
우리나라 미세먼지 해결방법

04_ 우리는 어떻게 대처할 것 인가?

04 우리는 어떻게 대처 할 것인가?

화력발전소 미세먼지 저감기술

화력발전소 국내외 규격 및 KIMM 목표

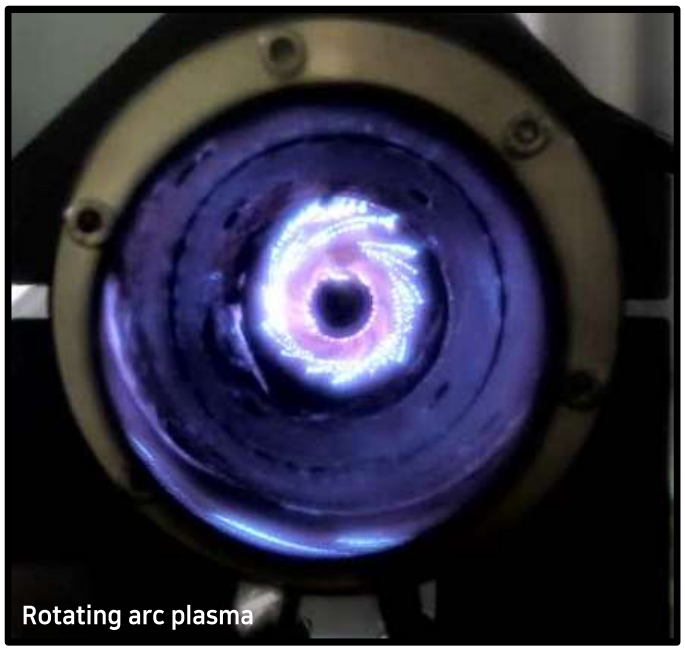
구 분	미국(신규)	국내(신규)	기계연(목표)
먼지(PM), mg/m³	12	5	1
질소산화물(NOx), ppm	46	15	8
황산화물(SOx), ppm	48	25	8

핵심원리 : Electrostatic

두산중공업 본사에 설치된 발전소용 Pilot 설비

04 우리는 어떻게 대처 할 것인가?

Rotating arc plasma



Rotating arc plasma

Fuel reforming & 2nd syngas combustion

30

04 우리는 어떻게 대처 할 것인가?

군용 트럭 매연저감사례

DPF + plasma burner

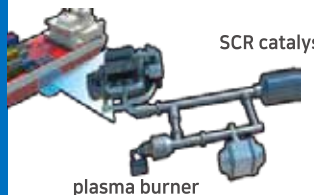
지난 1년간 총 18회 매연측정 결과
95%이상의 제거 성능

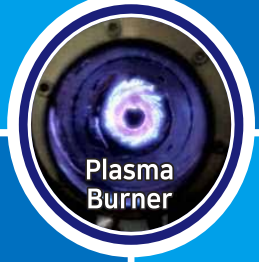
04 우리는 어떻게 대처 할 것인가?

Plasma burner 활용 대기정화 기술

군 특수차량
'19년도 추경예산 활용
군부대 실증

중대형 선박
선박엔진 및 조선기자재 업체
기술이전 및 제품개발 중





**발전소,
중화학 공장**
일산 복합 실증 종료
여수 소재 발전소 설치 추진

**반도체/
디스플레이 공정**
기술이전 및 제품개발 중
중국 반도체 공장에 적용

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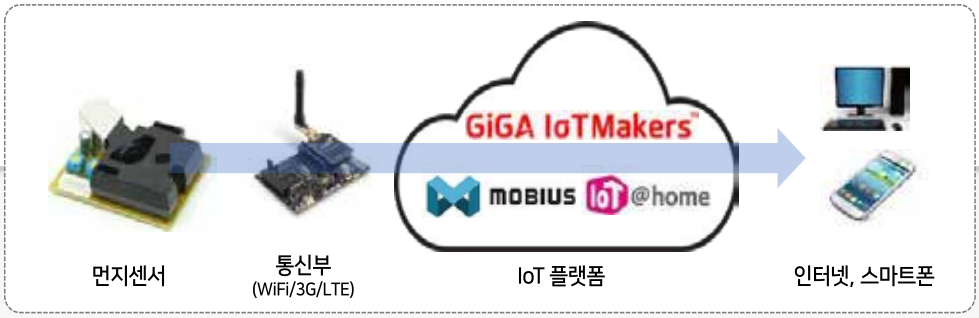
미세먼지 노출저감 기술

공기청정기 성능평가 및 인증

미세먼지 센서 및 예보 시스템 구축



미세먼지 어떻게 줄일까?

요 약

- 미세먼지는 산업화 과정에서 불가피하게 발생
- 선진국의 경우 1) 산업설비 고도화, 2) 저감기술 보급, 3) 산업구조 개편 등을 통해 미세먼지 문제를 해결
- 특히, 점 -> 선 -> 면으로 규제 및 관리 대상을 확대하고, 동시에 해외발생 미세먼지 및 원인물질을 공동으로 저감하는 노력이 필요
  - 국제 공통의 오염원 규제 및 정책, 저감 기술의 공유 및 지원
- 매우 강력한 미세먼지 저감기술개발 및 보급이 진행중
  예)Plasma 기술을 활용한 저감기술 : 발전소, 자동차, 선박 등
- 미세먼지는 우리가 피해자이면서 동시에 발생원이기도 하다

Note

Note

Note

Note

Note

SESSION 1

동북아와 미세먼지

전기집진기술의 현재와 미래

Electrostatic Precipitation: Present and Future

>> 중국 절강대(Zhejiang University) Keping Yan 교수

Keping Yan / Professor, Zhejiang University / China

Electrostatic Precipitation: Present and Future

Prof. dr. Keping Yan

Zhejiang University, Hangzhou, China

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.

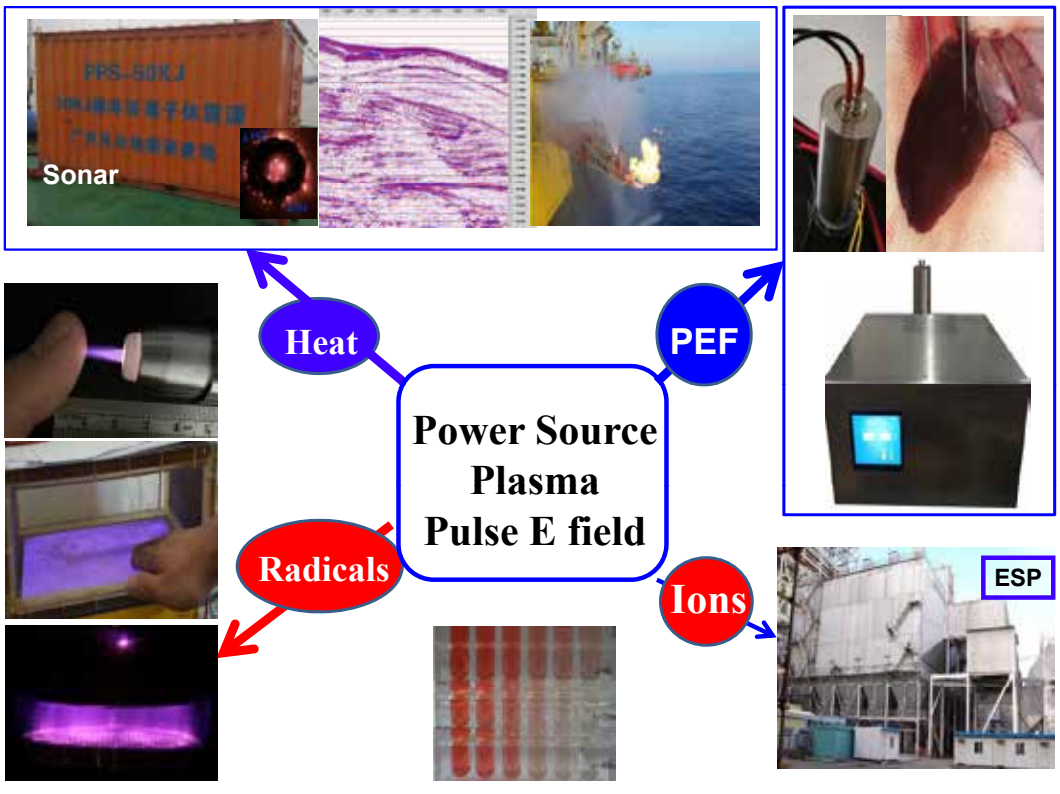
Since 2004, he has been a board member and the president (2008-2011) of the International Society of Electrostatic Precipitation (ISESP).

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/m^3
NOx: 450-1000mg/m^3
SO_2: 400-1200mg/m^3

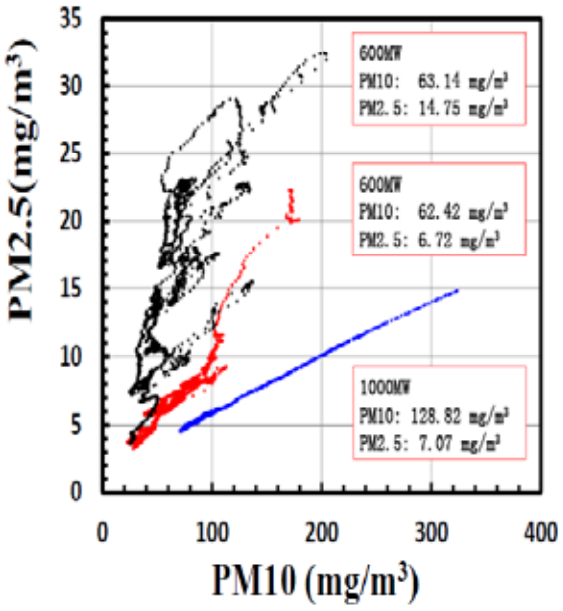
2011
PM: 30mg/m^3
NOx: 100-200mg/m^3
SO_2: 200mg/m^3

2014
PM: 20mg/m^3
NOx: 100mg/m^3
SO_2: 50mg/m^3

2015
PM: 10mg/m^3
NOx: 50mg/m^3
SO_2: 35mg/m^3

Today Region or Utility
PM: 1-5mg/m^3 NOx: 10-30mg/m^3 SO_2: 17mg/m^3

How to Size and Operate ESP?



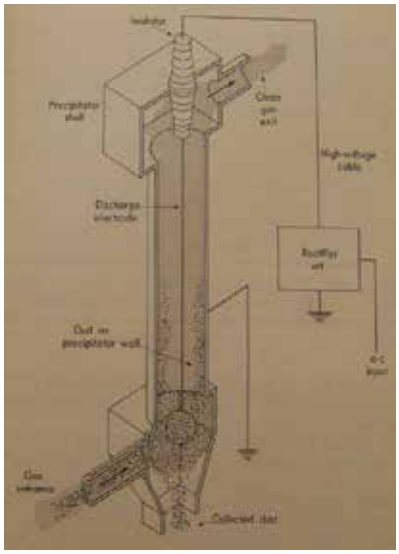
ESP outlet PM:
50-100 mg/Nm^3

How to control PM below 5 mg/Nm^3 ?

How to control PM2.5 to below 2.5 mg/Nm^3 ?

How to size and/or upgrade ESP ?

Principle of Electrostatic Precipitation



H.J. White, Industrial
Electrostatic Precipitation, 1963

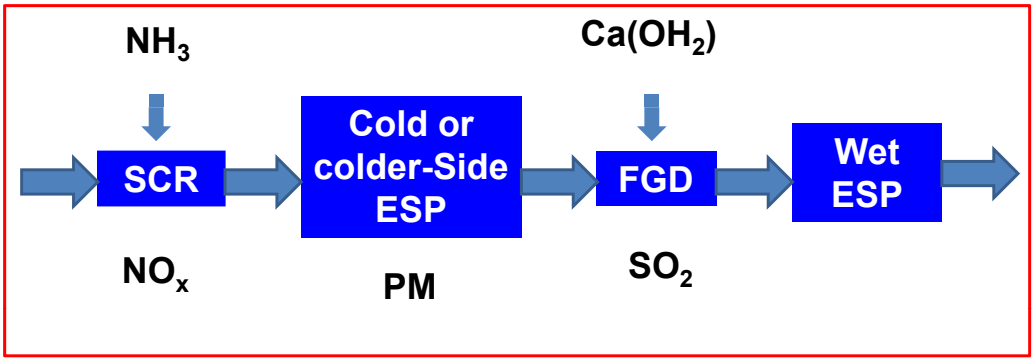
ESP & Gas Temp

1. T > 300ºC, hot-side ESP;
2. T > T(SO_3 dew point), cold-side ESP;
3. T < T(SO_3 dew point), colder-side ESP;
4. T < T(H_2O dew point), wet ESP

Gas Cleaning System

PM ≤ 10mg/m^3
NOx ≤ 50mg/m^3
SO_2 ≤ 35mg/m^3
Hg ≤ 3μg/m^3

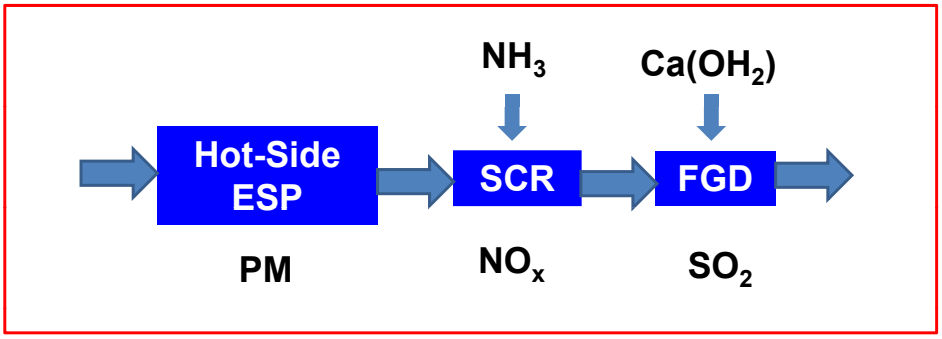
Coal-fired Power Plant



Gas Cleaning System

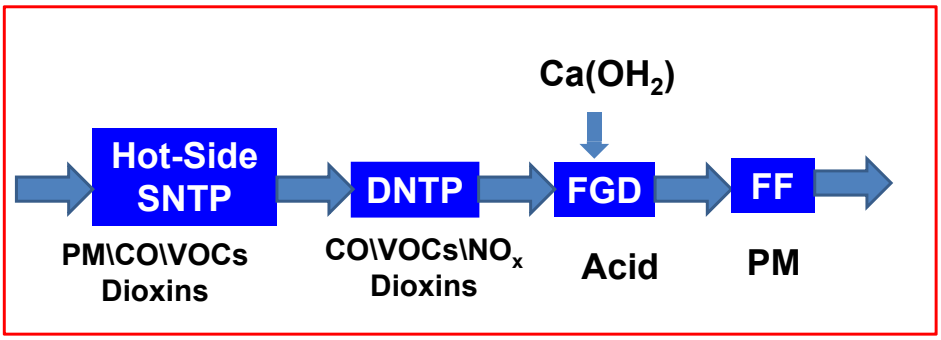
PM ≤ 10mg/m^3
NOx ≤ 50mg/m^3
SO_2 ≤ 35mg/m^3

Glass、coking and Cement Industries



Gas Cleaning System

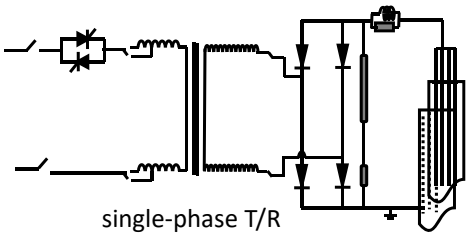
Solid waste incinerator



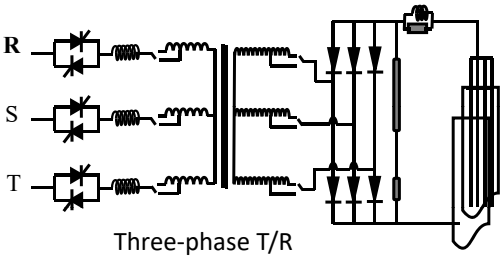
Modern ESP

600MW

HV Power Sources

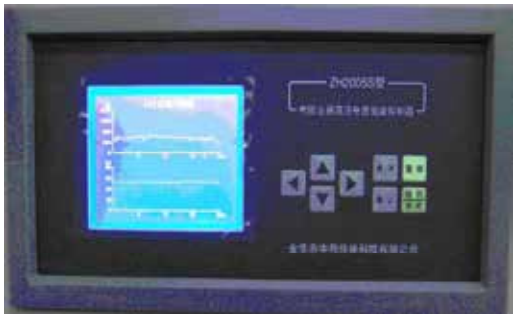


single-phase T/R

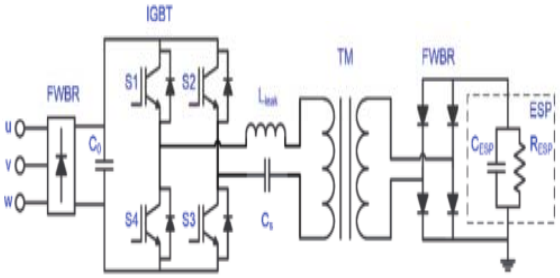


Three-phase T/R

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



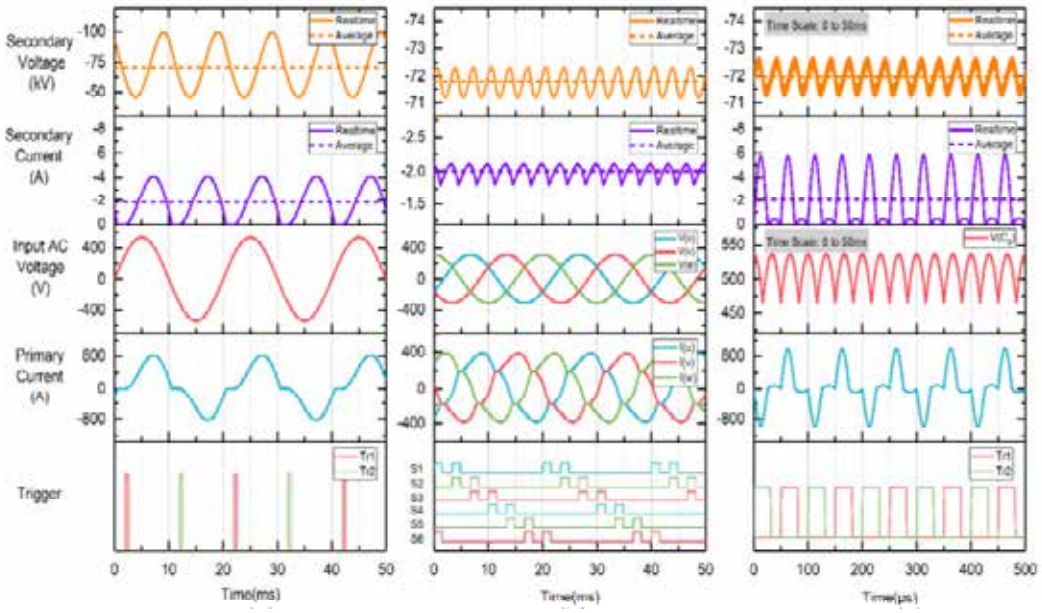
HV Power Sources



High-frequency Switch Mode Power Source

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

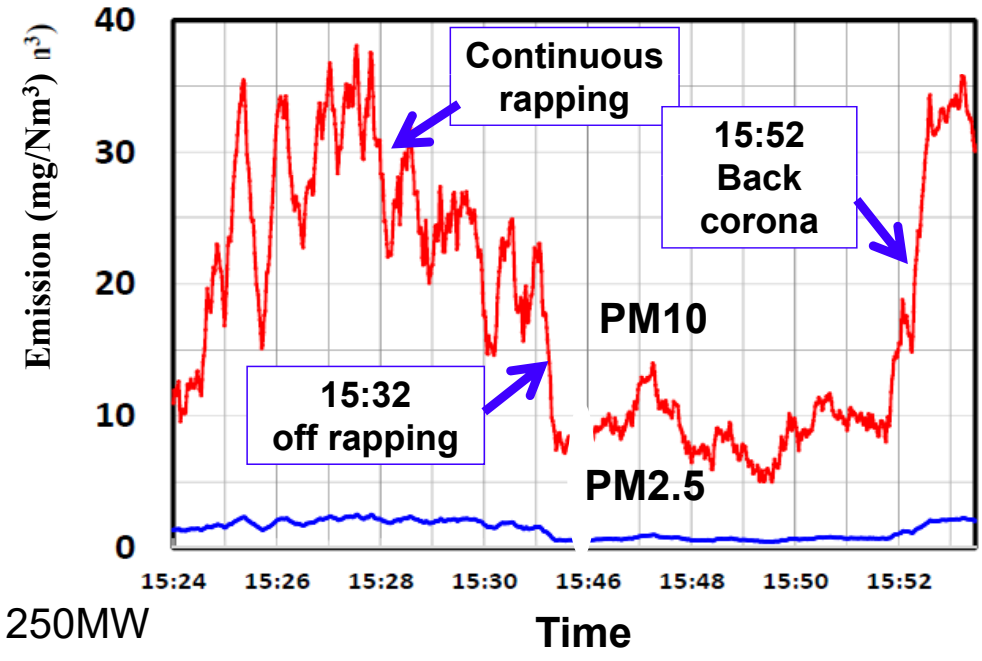
Waveforms of HV Power Sources



Single-phase **Three-phase** **Switch-mode**

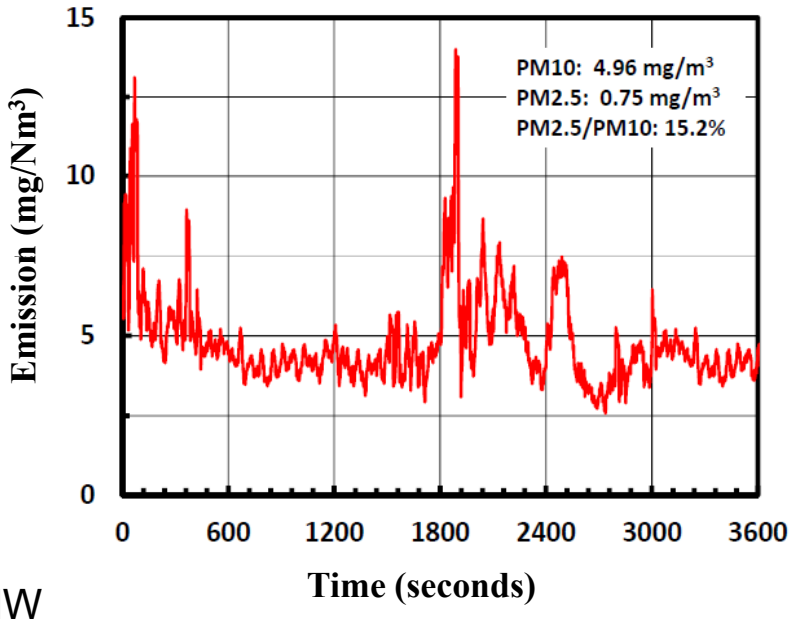
Ash Collection on Electrodes

Colder Side ESP via 1st Field Rapping



250MW

PM10 Emission of Colder Side ESP



300MW

Modern Chinese ESP: 2x1100MW

Temperature: 90-120°C

Ash Inlet load: ~ 30g/m³

ESP

SCA: ~ 136m²/m³/s

HV: 60 three-phase T/R

How to Size and Operate ESP?

Traditional Matts & Ohnfeldt's Methods

Emission

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

$$k \approx 0.5$$

ω_k

Coal or ash

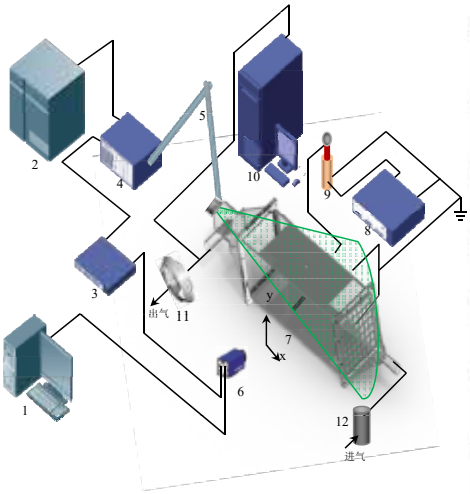
ω_k migration velocity (m/s)

S collection area ($m^2/m^3/s$)

Collection area

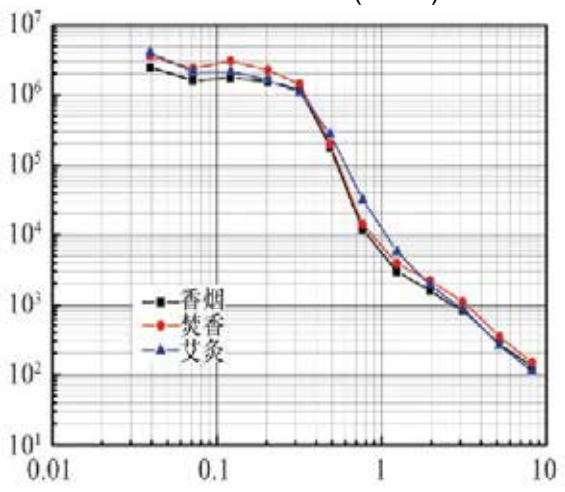
Matts S. and Ohnfeldt P.O. (1963) Efficient gas cleaning with SF electrostatic precipitation, SF Rev 1963-1964, 6,7, 105-22

ESP Sizing Model and PIV Observations



ESP: 200x200x400mm^3

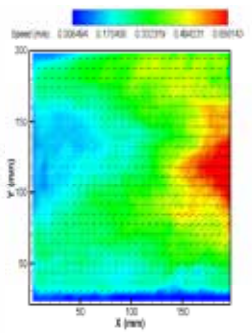
Number Concentration (1/cm^3)



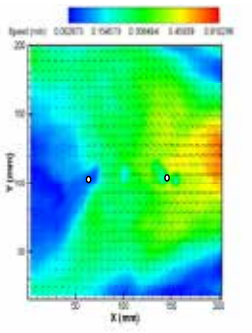
Particle diameter (μm)

ESP Sizing and PIV

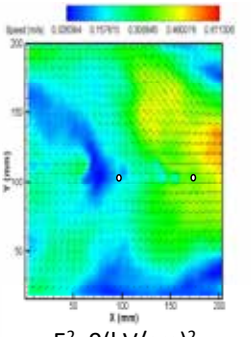
200x200mm^2



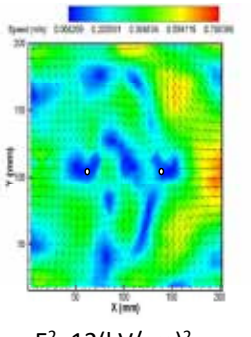
E^2=0



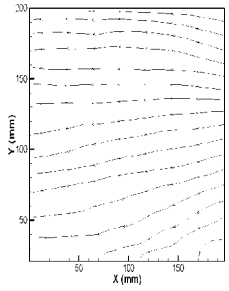
E^2=6(kV/cm)^2

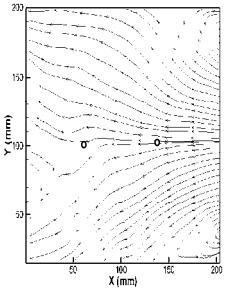


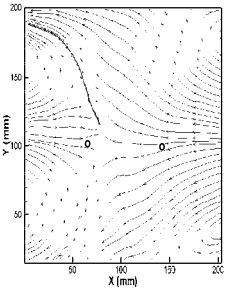
E^2=9(kV/cm)^2

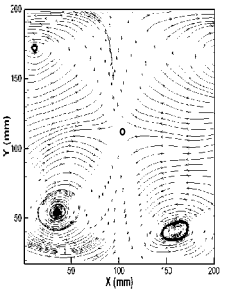


E^2=12(kV/cm)^2



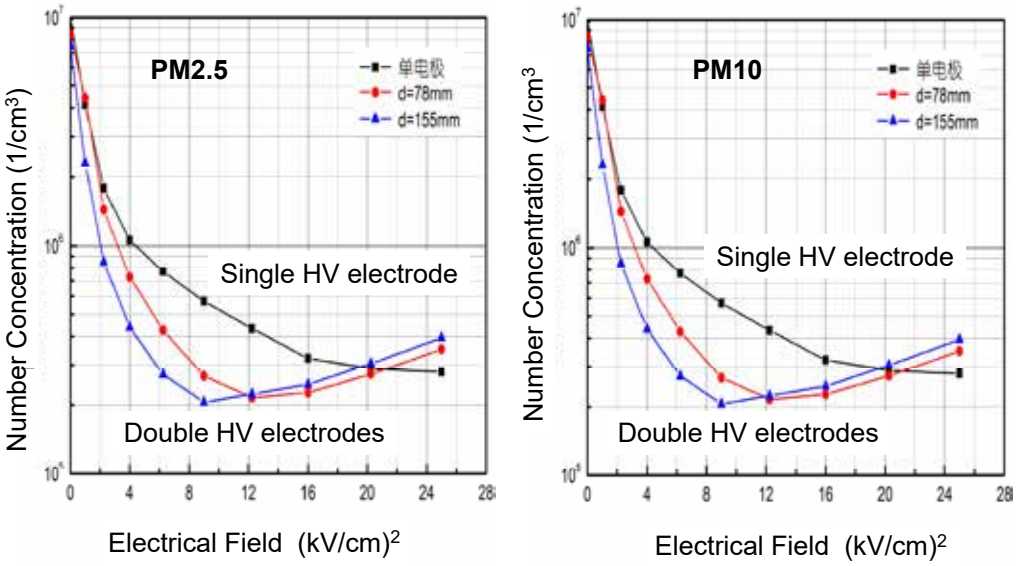




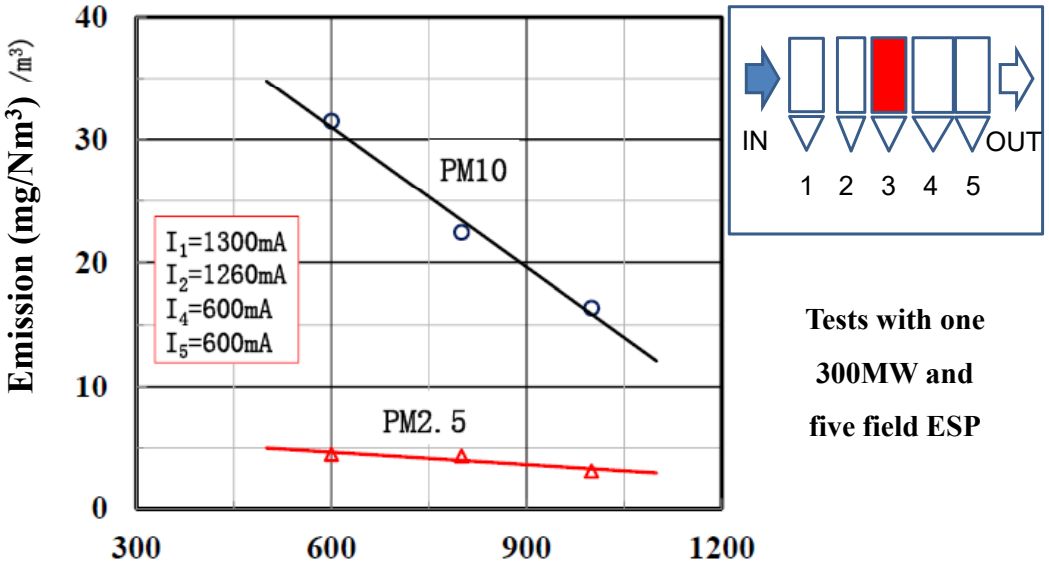


ESP Emission via Field Strength

Grade Collection via their Numbers



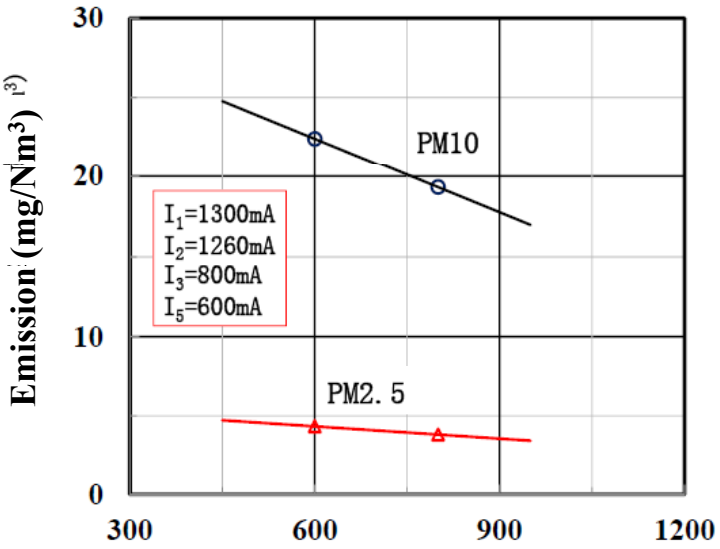
ESP Performance via Field Current

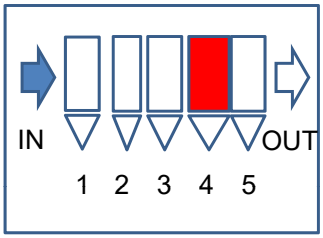


Tests with one 300MW and five field ESP

Huang Y. et al, IJPEST 2015

ESP Performance via Field Current





Tests with one 300MW and five field ESP

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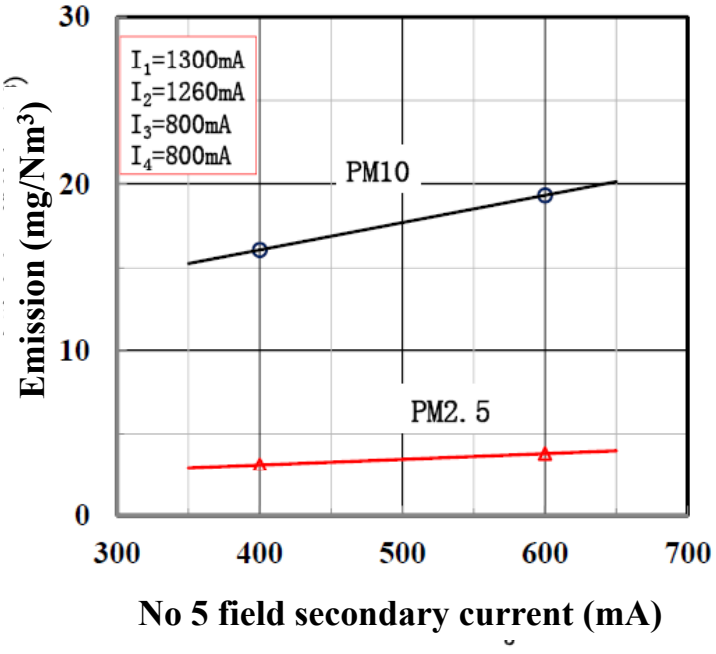
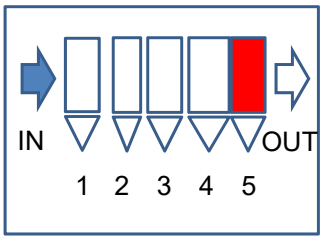
ESP Performance via Field Current





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
$E_a \cdot E_p$

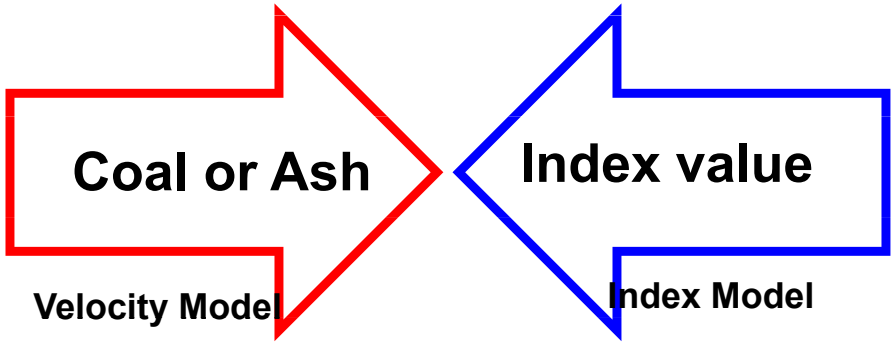
Specific Area
S

ESP Size
Gas flow rate

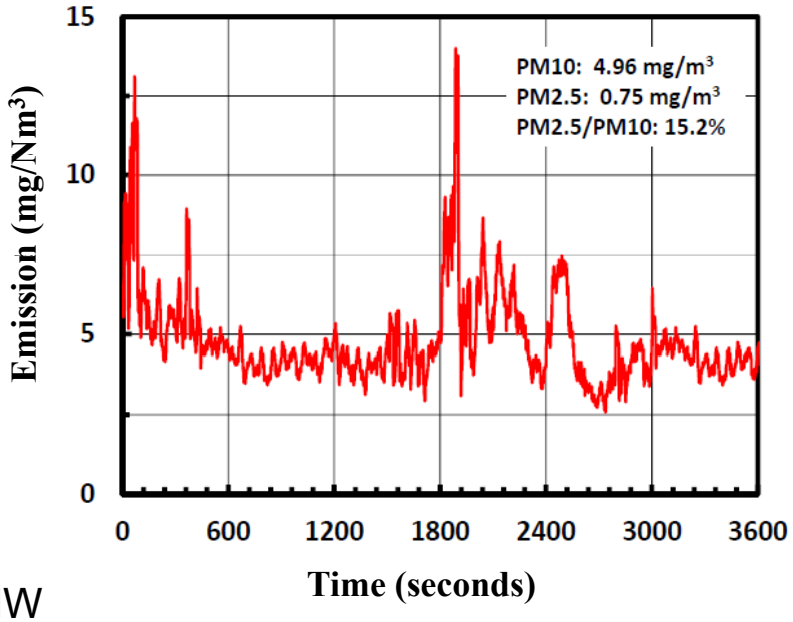
Zhu J. et al, Journal of Electrostatics, 2012

How to Size and Operate ESP?

From Migration Velocity to the Index Value



PM10 Emission of Colder Side ESP



300MW

Modern Chinese ESP: 2x1100MW

Temperature: 90-120°C

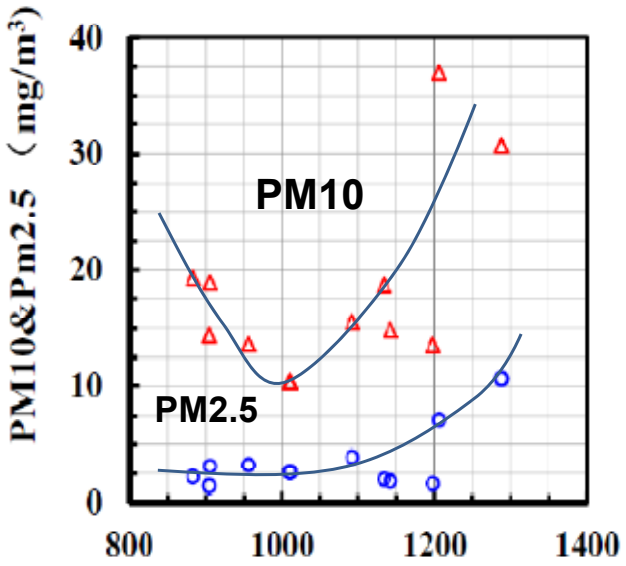
Ash Inlet load: ~ 30g/m^3

ESP

SCA: ~ 136m^2/m^3/s

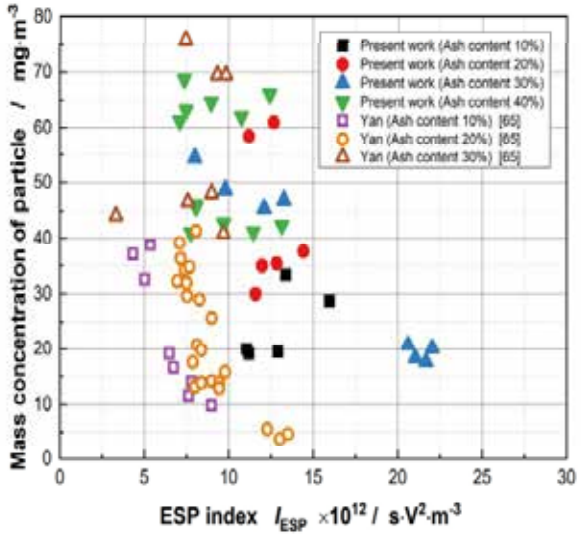
HV: 60 three-phase T/R

PM2.5&PM10 via the HV Input Power



2x660MW

ESP Outlet PM Emission

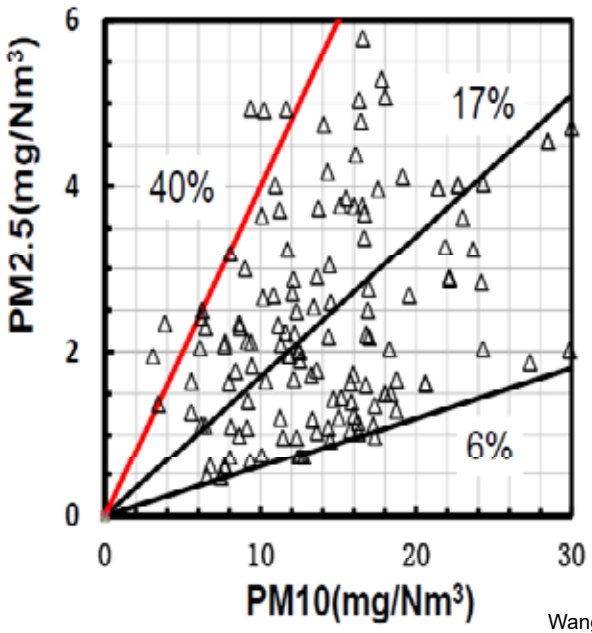


$$\lg\frac{m}{\beta \cdot M_0} = -\alpha \cdot E_a \cdot E_p \cdot S$$

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

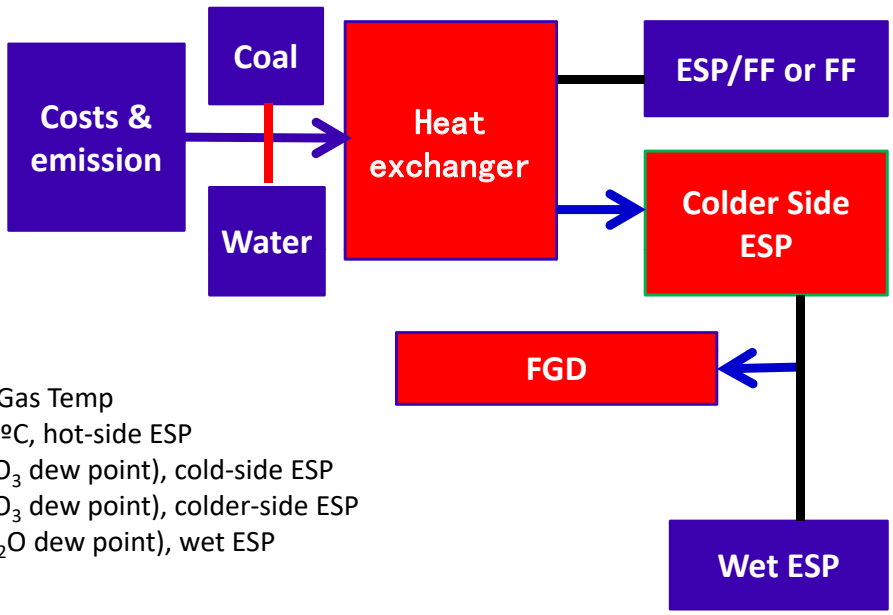
PM2.5 via PM10 at ESP Outlets



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

Wang S. et al, Sci & Tech Review 2014 (32),33

Near Zero Emission Control



ESP & Gas Temp
T> 300ºC, hot-side ESP
T> T(SO_3 dew point), cold-side ESP
T< T(SO_3 dew point), colder-side ESP
T< T(H_2O dew point), wet ESP

Application: 75t/h Boilers – HV sources

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:

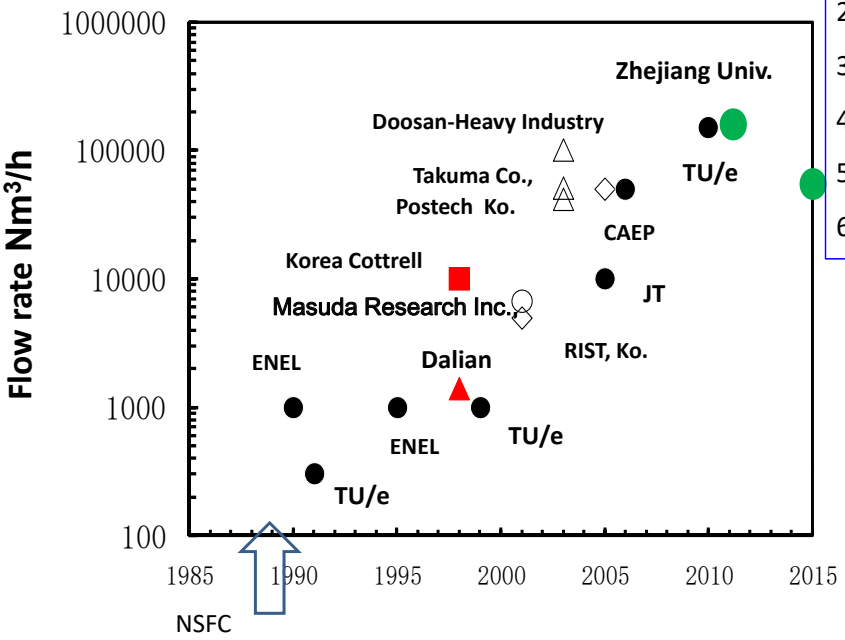
- 4x4 or 4x5 bus sections
- 16 or 20 HV power sources
- 1200mA (2000mA) &82kV

1000-1100 MW Boiler:

- 6x4 or 6x5 bus sections
- 24 or 30 HV power sources
- 2000mA &82kV

New one: 2x3x10 bus sections

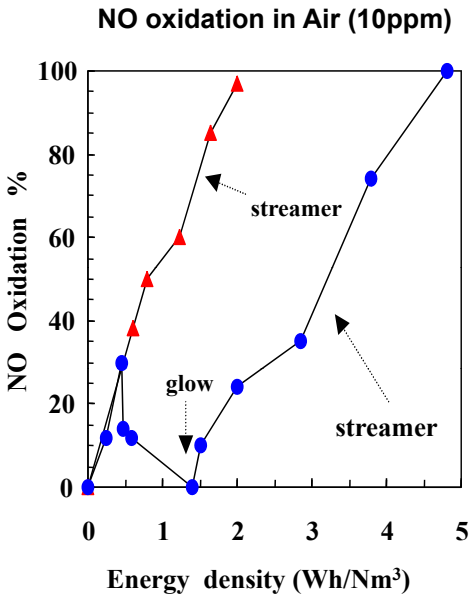
Some NTP Demonstrations



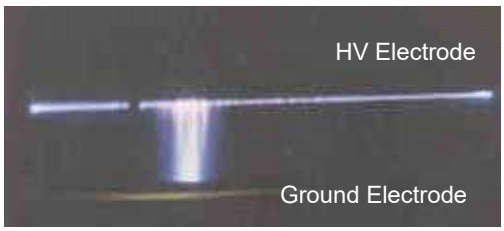
2017

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

Discharge Modes and Chemical Reactivity



Positive corona discharge in air



Reactions: Streamer

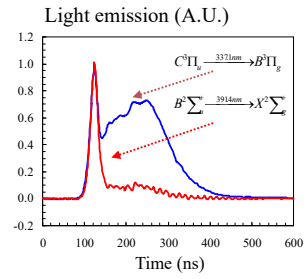
Charging: glow or streamer

K.Yan, et al, Trans IEEE-IAS, 2001

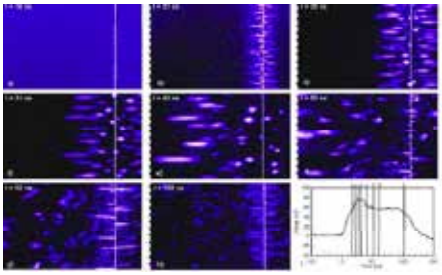
Electrical Discharges and Processes

Streamer Corona

SNTP



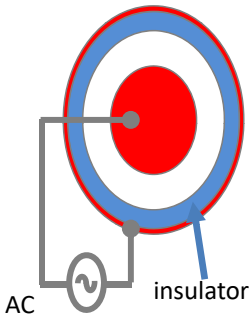
K. Yan, et al, ISPC 1993



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

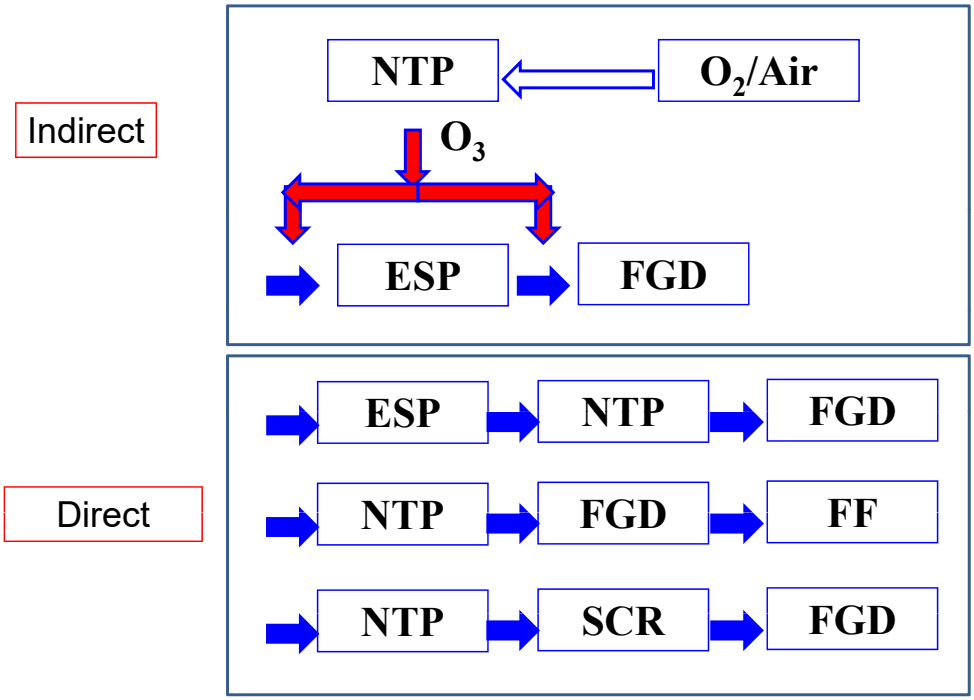
Dialectical Barrier Discharge

DNTP



200-400kVA
Introduced to market in 2017

NTP for DeNOx & DeSO$_2$ & PM



O_3 Oxidation NO - FGD

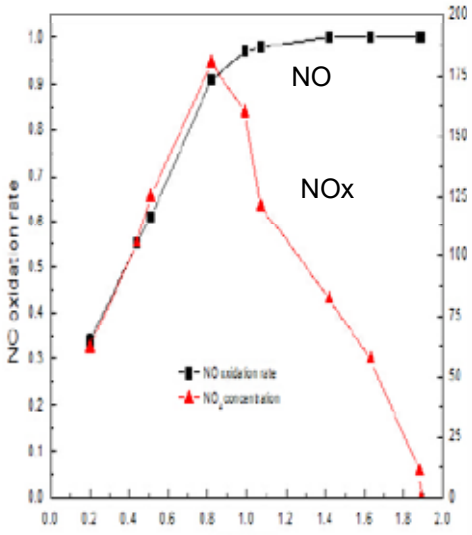
3x130t + 2x220t + 1x450t = 1280 t

1. ESP+O_3+FGD
2. O_3: 240kg/h
3. NOx efficiency≥70%
4. O_3/NO: 1.2-1.4
5. NOx ≤ 50mg/m^3
6. P ~ 2600 kVA
7. O_2: 2400kg/h

Indirect NTP Gas Cleaning

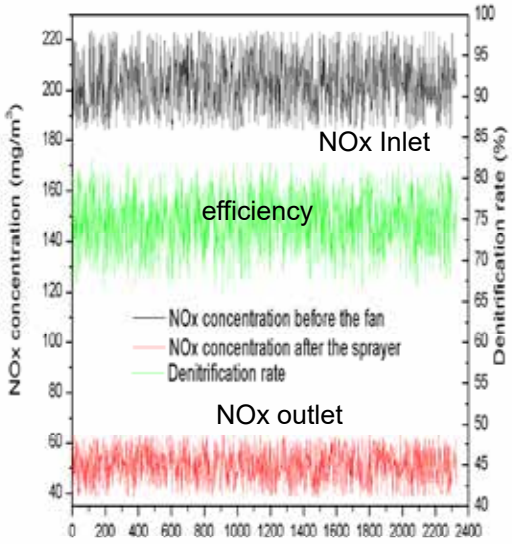
35 t/h & 85,000m^3/h

Before FGD



O_3/NO

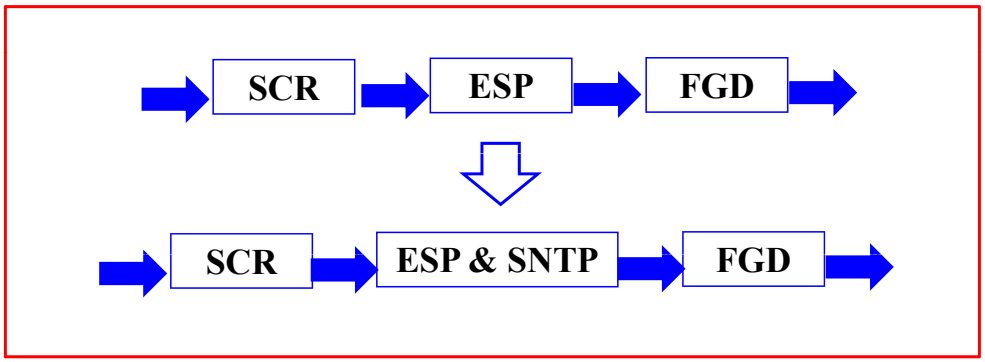
After FGD



Operation (H)

SCR-ESP & SNTP-FGD

Demonstration with 660MW



ESP to NTP Upgrading:

660MW

PM ≤ 15 mg/m³

	1, 2 FIELDS	3 FIELD	4 FIELD	5 NTP
PM	≤120mg/m³	≤ 50mg/m³	≤ 20mg/m³	≤ 15mg/m³

NOx

Δ ≥ 20mg/m³

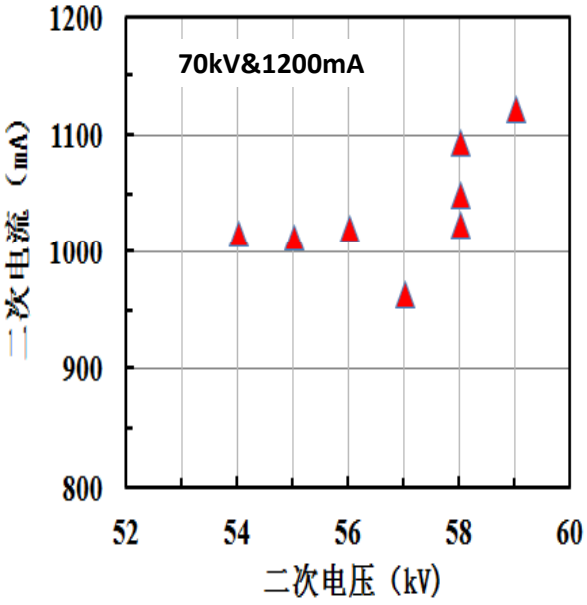
Δ ≥ 40mg/m³

Δ ≥ 60mg/m³

SCR: 40-80mg/m³ → < 20mg/m³

SCR-ESP & SNTP-FGD

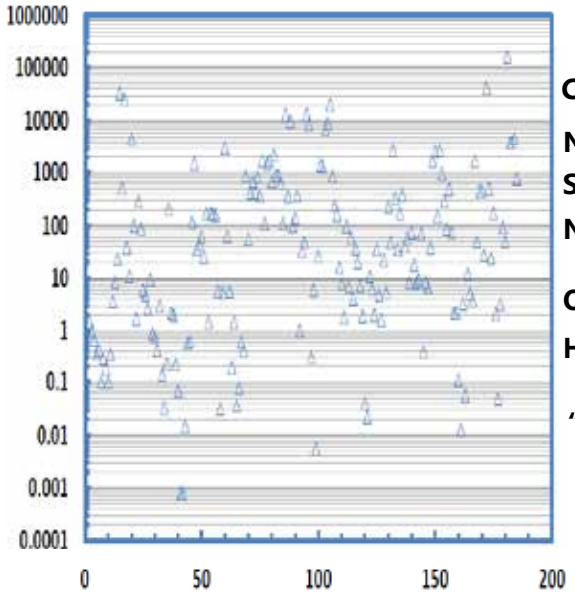
8 SNTP POWER SOURCES



SNCR+ESP+DNTP+FGD

75t/h

Odor Thresholds （ppb）



CH_3OH 33ppm

NH_3 1.5ppm

SO_2 870

NO_2 120

O_3 3.2

H_2S 0.4

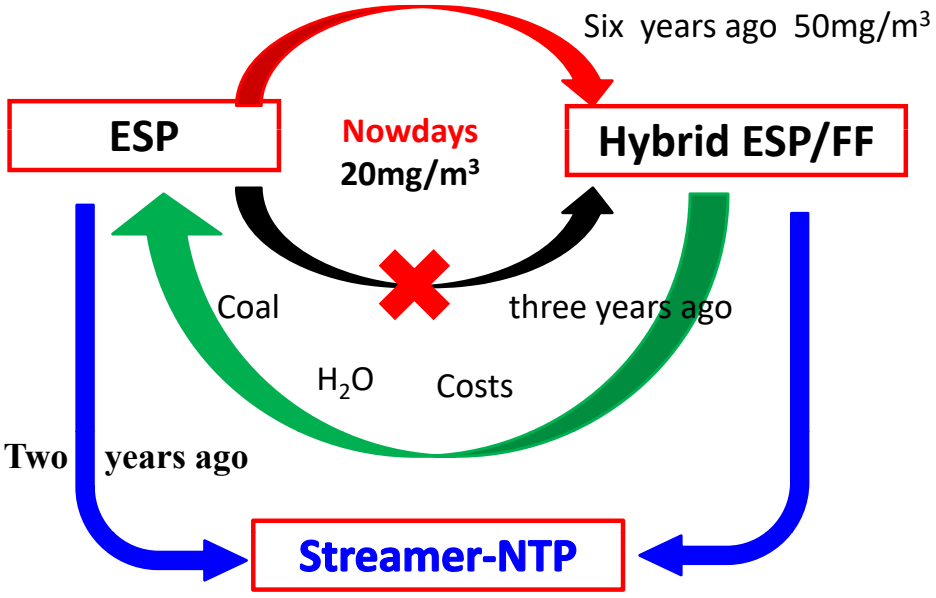
"S" related

2x100kVA DNTP

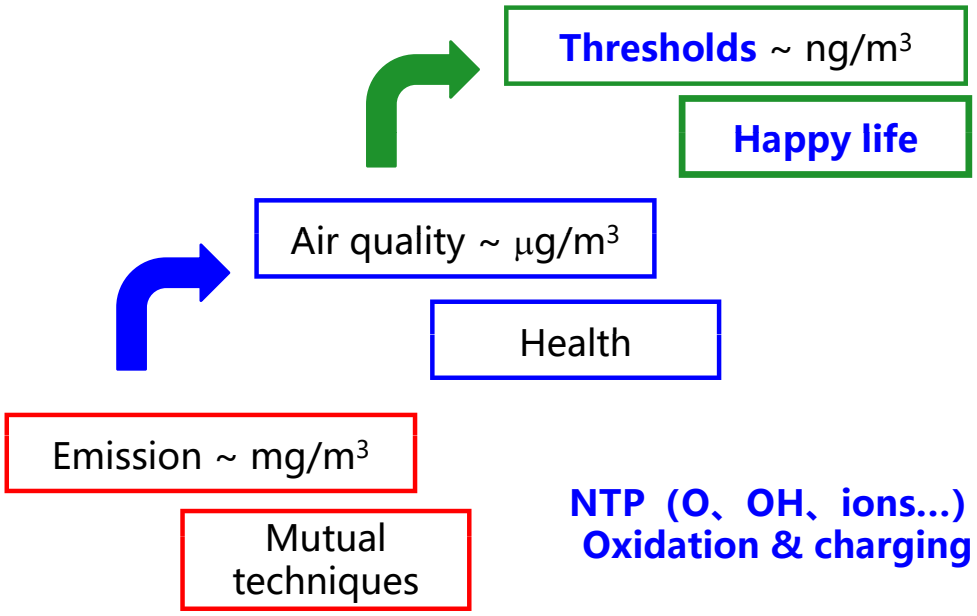
250000m^3/h

NH_3, H_2S, CS_2

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**

Note

Note

Note

Note

Note

SESSION 3

동북아와 미세먼지

일본의 산업공해 관리

Control of Industrial Air Pollution in Japan

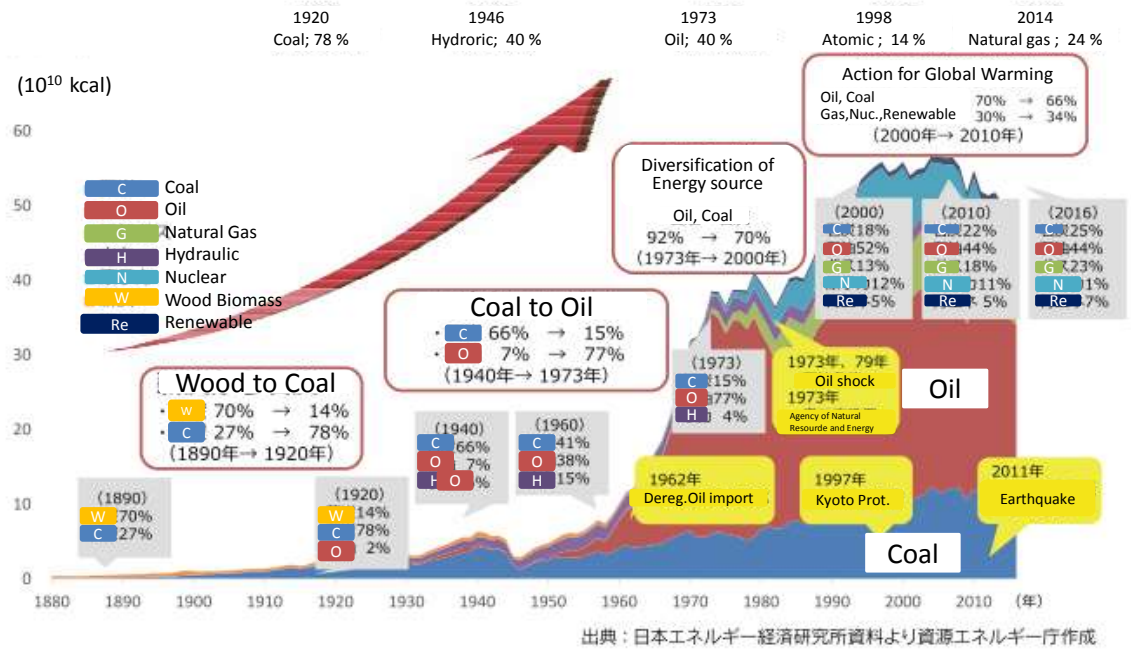
>> 일본 도요하시 기술과학대(Toyohashi University of Technology)
Akira Mizuno 명예교수 (前 일본 정전기학회장)

Akira Mizuno / Professor Emeritus,
Toyohashi University of Technology / Japan

Control of Industrial Air Pollution in Japan

Dr. Akira Mizuno
Professor Emeritus–
Toyohashi University of Technology
Japan

Change of the primary energy source in Japan



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

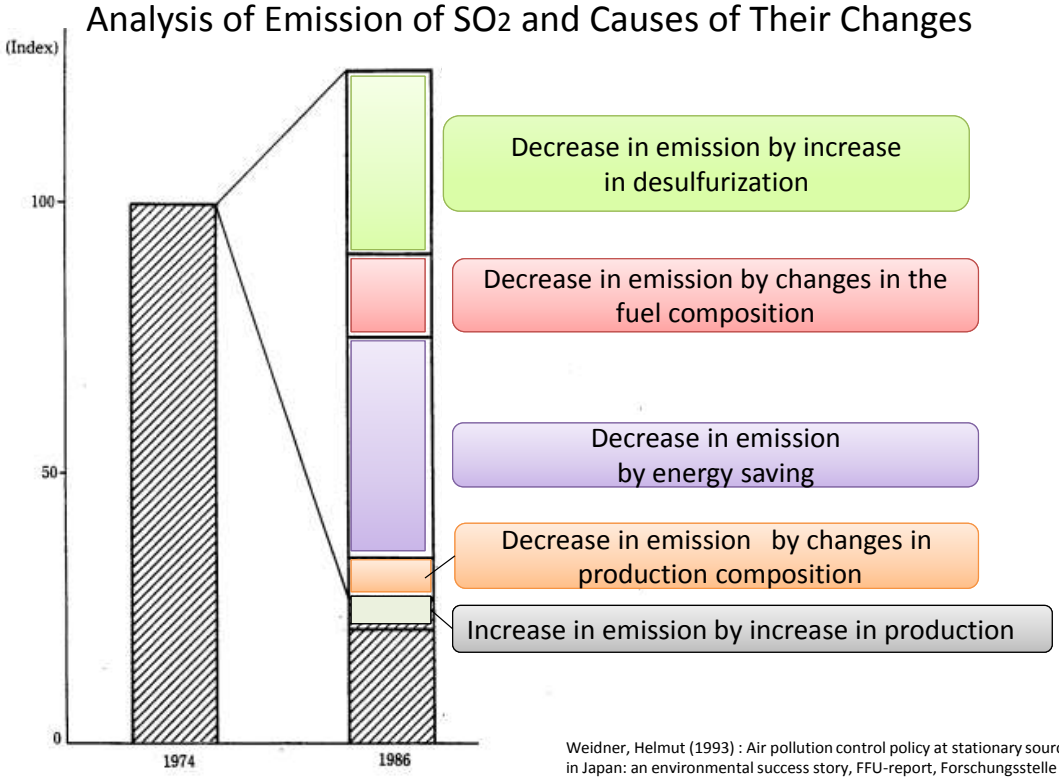
After Meiji restoration, modern industrialization started. Then, pollution became serious problem. With growing in pollution opposition movements nationally, the government in 1967 enacted the Basic Law for Environmental Pollution Control.

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.

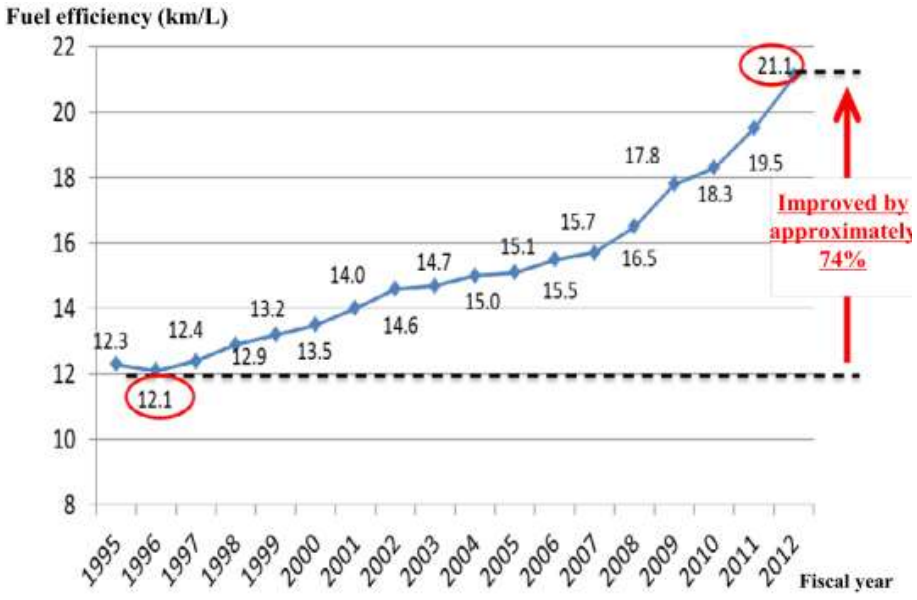
Analysis of Emission of SO_2 and Causes of Their Changes



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

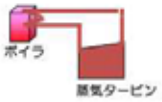
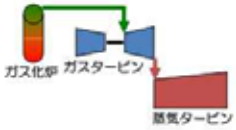
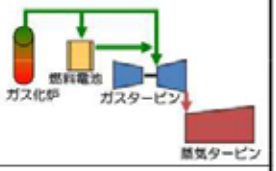
Weidner, Helmut (1993) : Air pollution control policy at stationary sources in Japan: an environmental success story, FFU-report, Forschungsstelle für Umweltpolitik, Freie Universität Berlin, No. 93-6, Forschungsstelle für Umweltpolitik, Freie Universität Berlin, Berlin

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



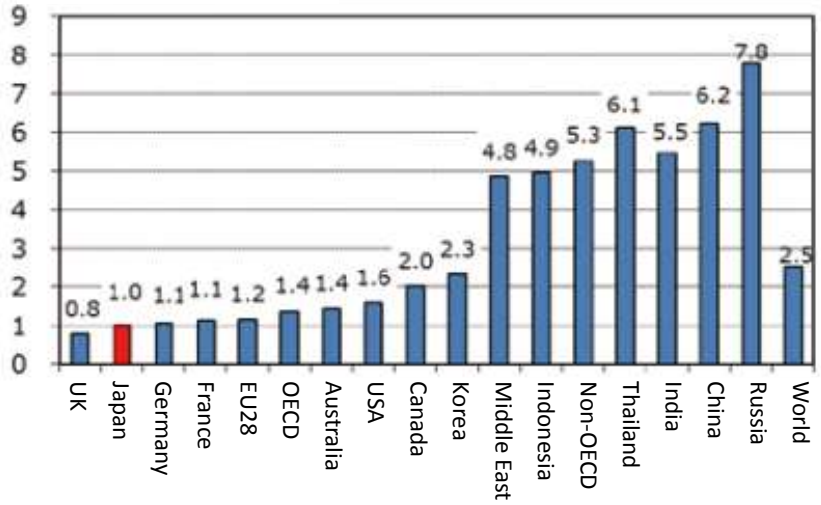
○ Changes in the average 10-15 mode fuel efficiency of gasoline fueled passenger cars
[Source] Created based on the data from the Ministry of Land, Infrastructure, Transport and Tourism

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

Primary energy supply / GDP
(Japan = 1)



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

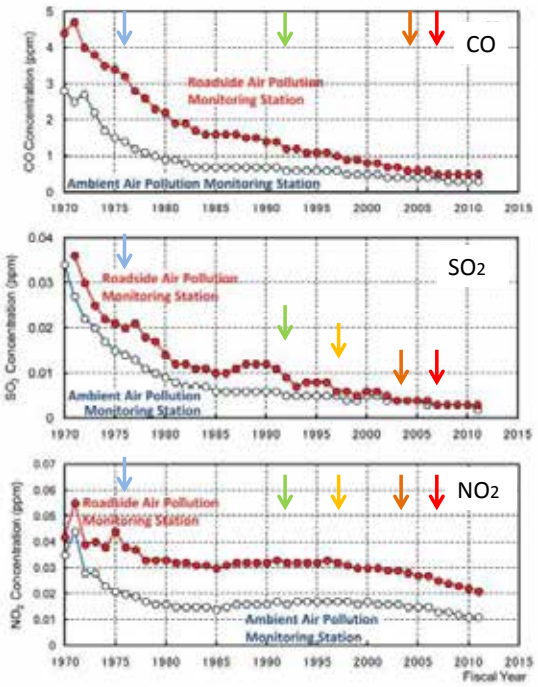
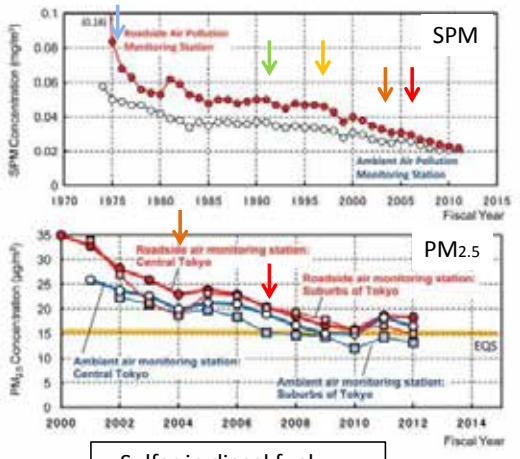


Fig. 2. Annual average concentrations of CO, SO_2, and NO_2 (1970-2012).



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)

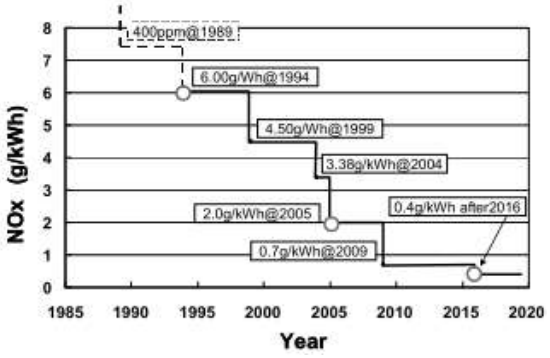
  (Establishment of Environment Agency (1971))
- Law Concerning Special Measures for the Conservation of Lake Water Quality(1984)
- Automobile NOx Law (1992)
- Environment Basic Law (1993)

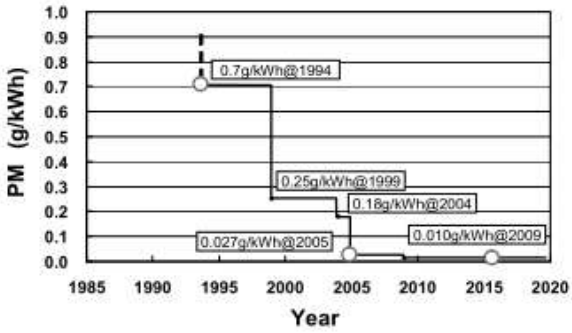
  (Inauguration of the Ministry of the Environment (2001))
- Automobile NOx PM Control Law (2001)
- Amendment of Air Pollution Control Law and Water Pollution Control Law (2010)

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

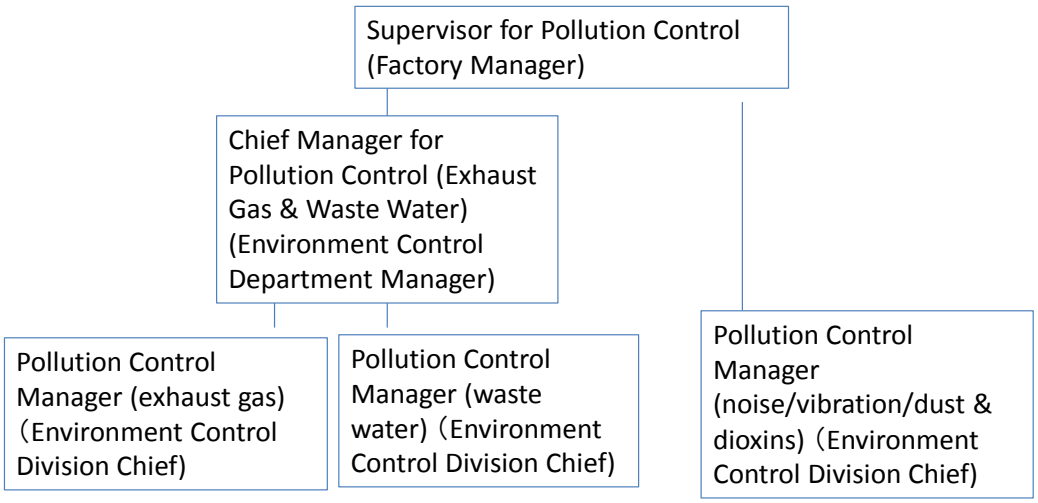
Environmental Standards	
CO	The daily average for hourly values shall not exceed 10 ppm (12 mg/m^3), and average of hourly values for any consecutive eight hour period shall not exceed 20 ppm (23 mg/m^3).
SO_2	The daily average for hourly values shall not exceed 0.04 ppm (105 μg/m^3), and hourly values 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)



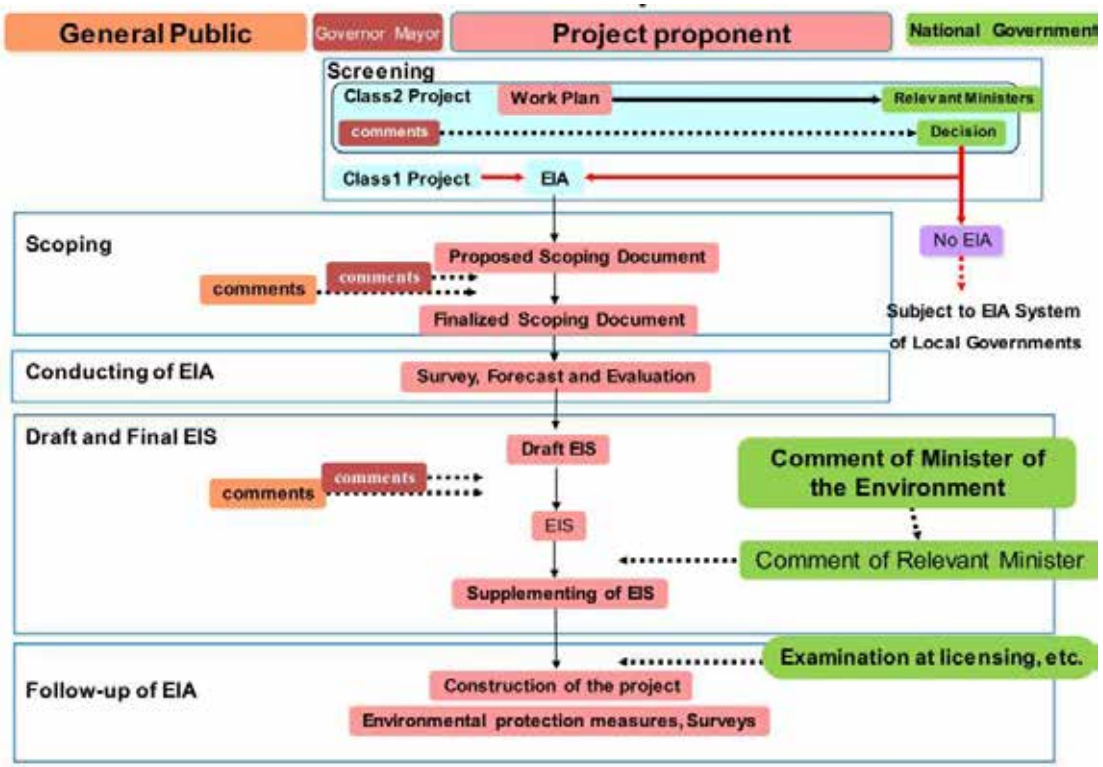
Efforts by the Private Sector

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

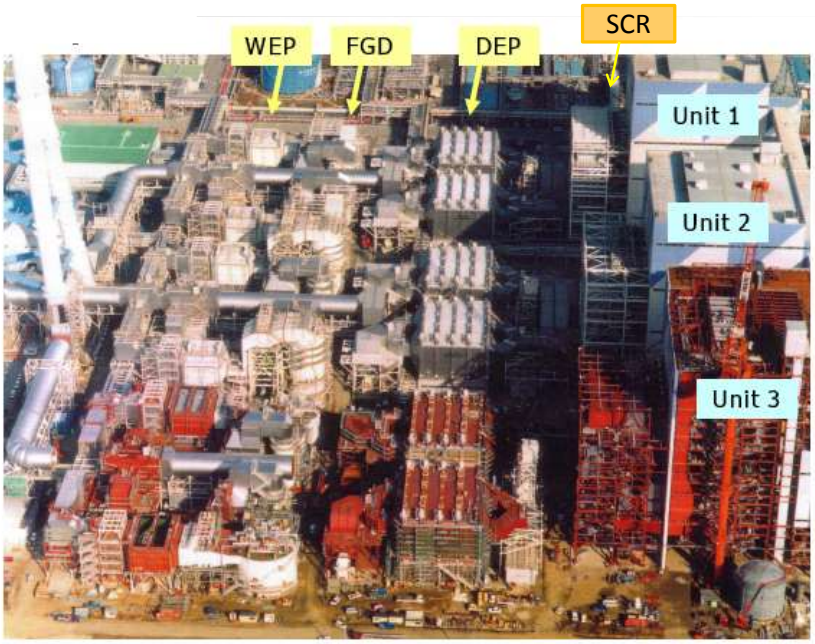
Functions of the Agreement

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



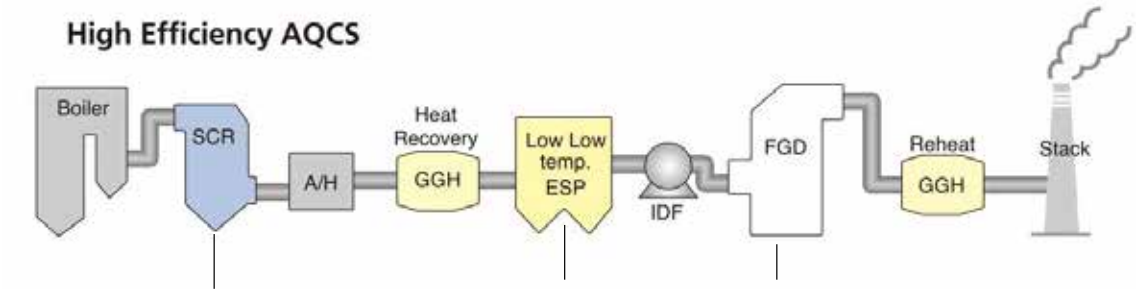
Flue gas cleaning system for coal fired electric power generation



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

MHI Co. Ltd

An Example of modern flue gas cleaning system



NO removal
Catalytic reduction

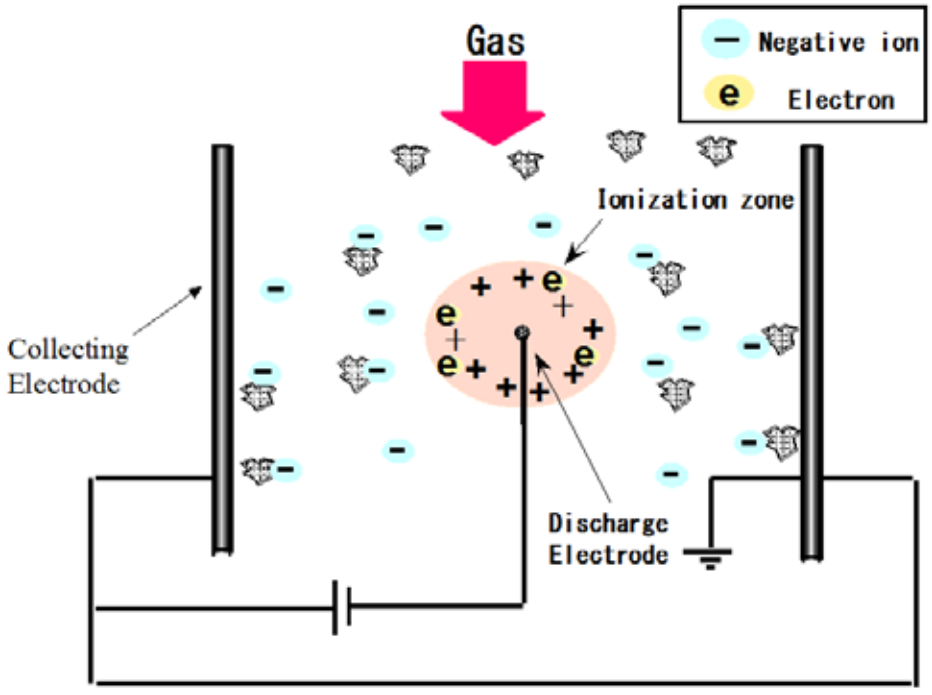
Dust removal

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.

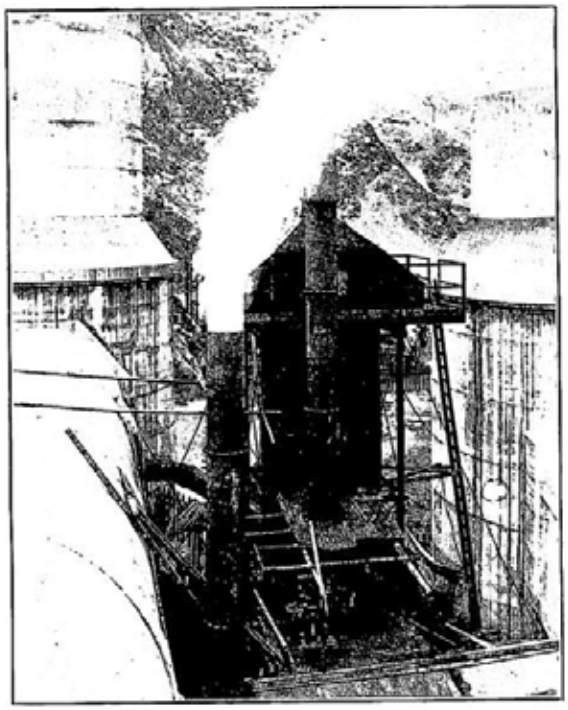


Figure 1.
Experimental Treater at Ashio, Electrical Current Off.

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

電極を絶緣物にて覆ひたる電氣沈澱裝置に就て

(On the Precipitation Treater with Glass-covered Electrodes)

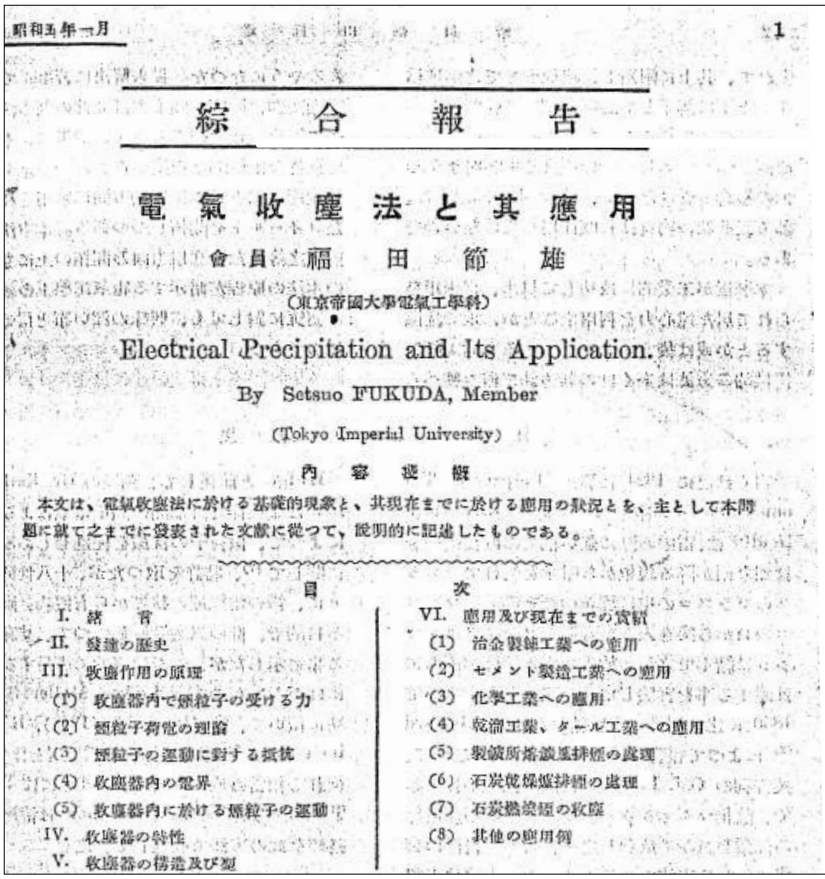
(大正十年四月東京支部演說豫稿)

會員 工學博士 澁 澤 元 治
會員 工學士 丹 羽 保 次 郎

內 容 梗 概

電極を絶緣物にて覆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振動、電極間の放電、コロナ狀態、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最初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緣物を通じて流るゝ現象につき考究し其の原因を絶緣體の溫度及び電位傾度によりて其の抵抗が減少すること及び絶緣體の表面に自由荷電を生じて絶緣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。

電極を絶緣物にて覆ひたる電氣沈澱裝置に就て



昭和五年一月 1

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)

内 容 梗 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。

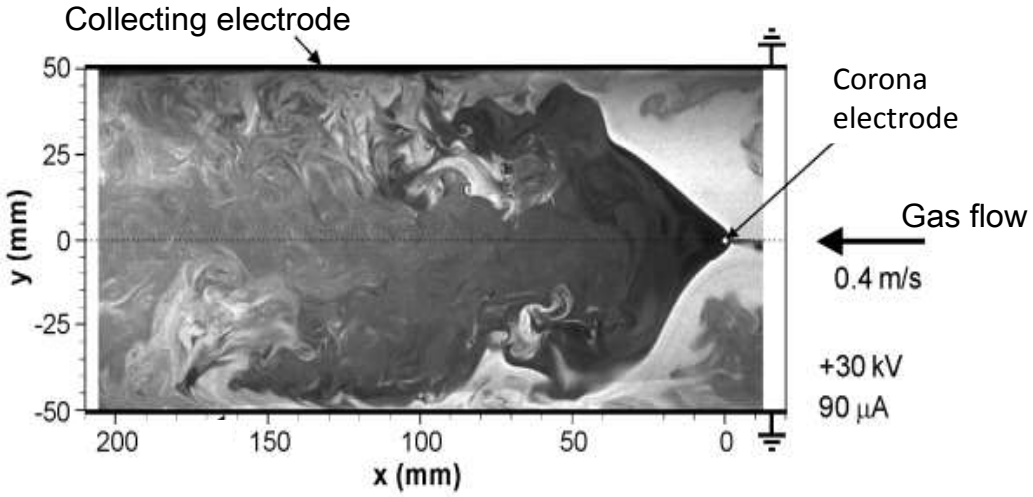
目 次

I. 緒 言
II. 發達の歷史
III. 收塵作用の原理
(1) 收塵器内で塵粒子の受ける力
(2) 塵粒子荷電の理論
(3) 塵粒子の運動に對する抵抗
(4) 收塵器内の電界
(5) 收塵器内に於ける塵粒子の運動
IV. 收塵器の特性
V. 收塵器の構造及び型
VI. 應用及び現在までの實績
(1) 冶金製鍊工業への應用
(2) セメント製造工業への應用
(3) 化學工業への應用
(4) 乾溜工業、タール工業への應用
(5) 製鐵所熔鑛爐排瓦の處理
(6) 石炭乾燥爐排瓦の處理
(7) 石炭燃燒爐の收塵
(8) 其他の應用例

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

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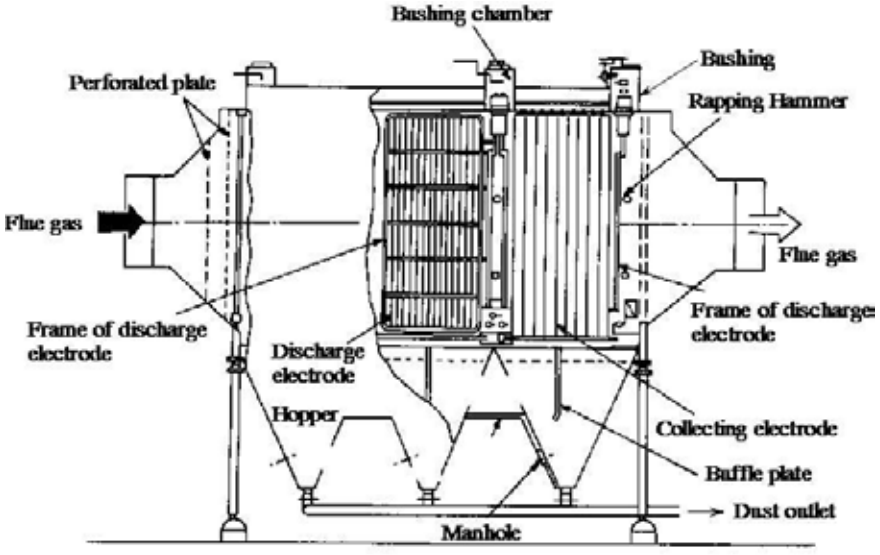
Typical construction of plate type electrostatic precipitator

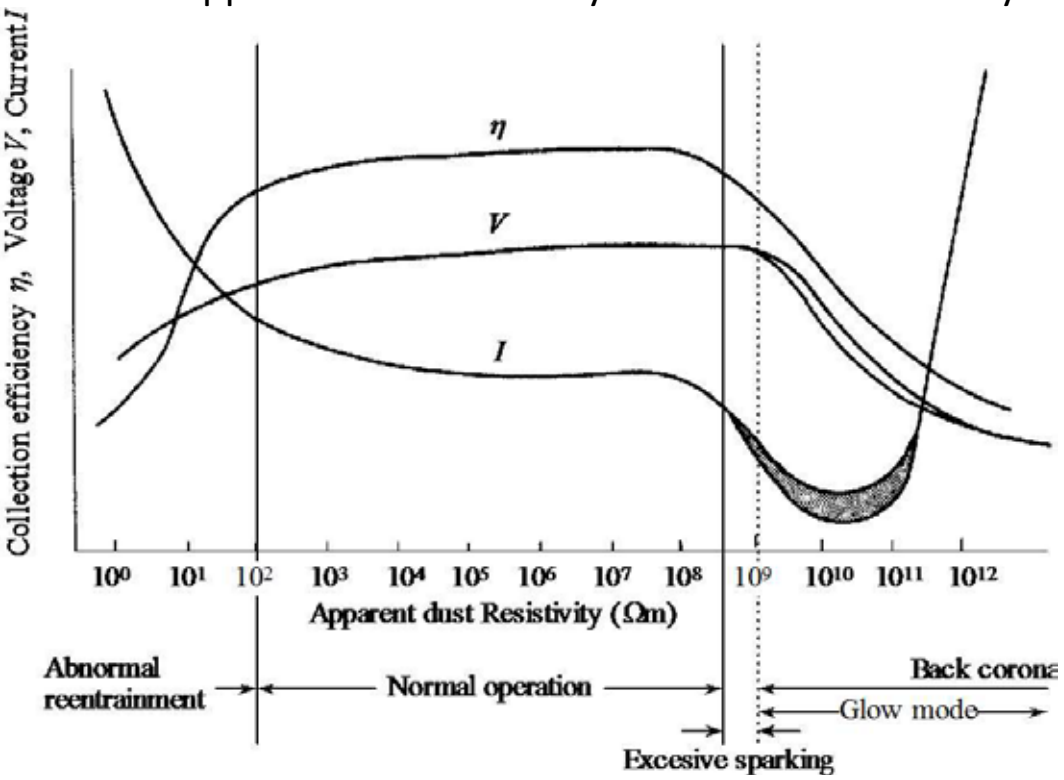


This figure shows a plate type ESP consisting of parallel plate electrodes for dust collection. The discharge electrodes are located between the plates. The gas flow is horizontal. This is a dry, one stage ESP. This type is used commonly in many industrial applications

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 $\rho d > 5 \times 10^8$ ohm-m, back corona takes place. For these extremely low or high resistivity dusts, the collection performance decreases.

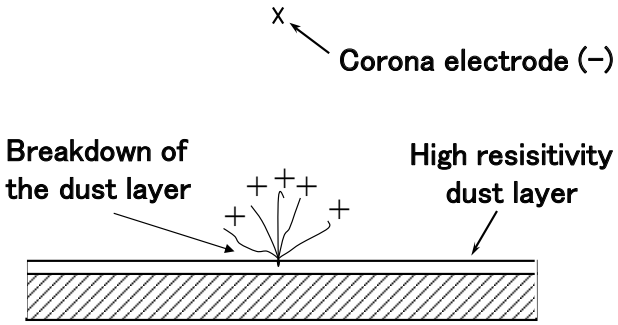
Effect of apparent dust resistivity on collection efficiency



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)



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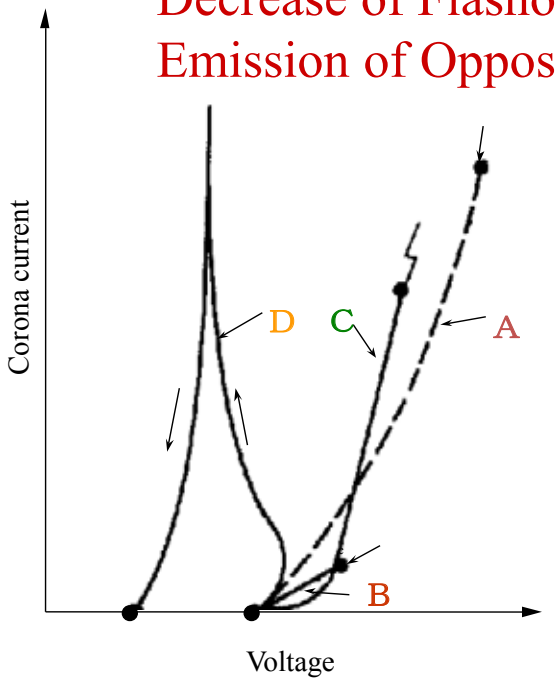
Back Corona

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

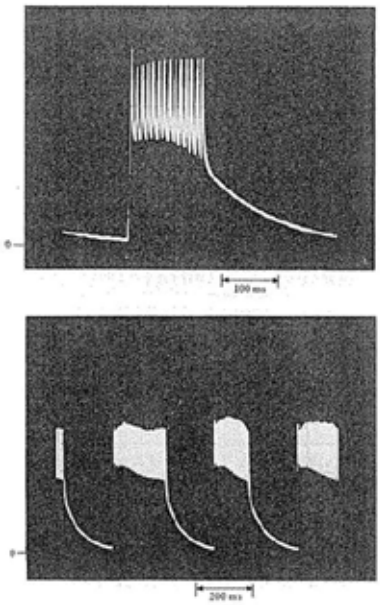
Uniform current distribution

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

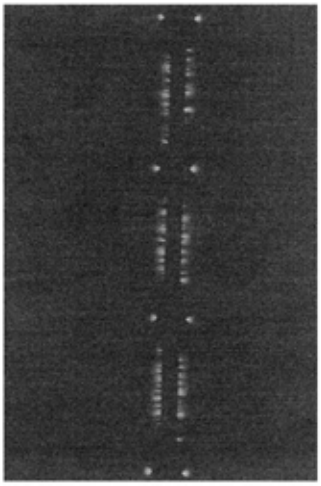
Control of Voltage waveform for Back corona

(Sumitomo-Heavy Industries)

Pulse voltage



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



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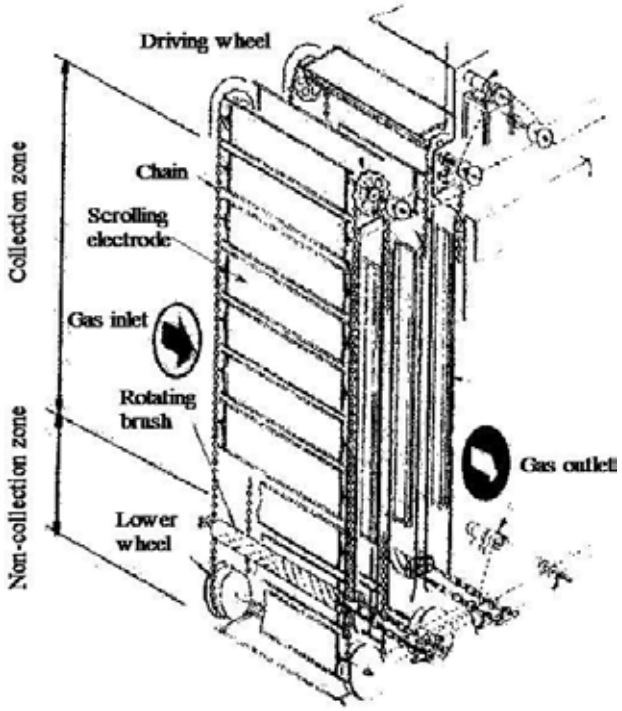
Comparison of the performance with DC and Pulse energization

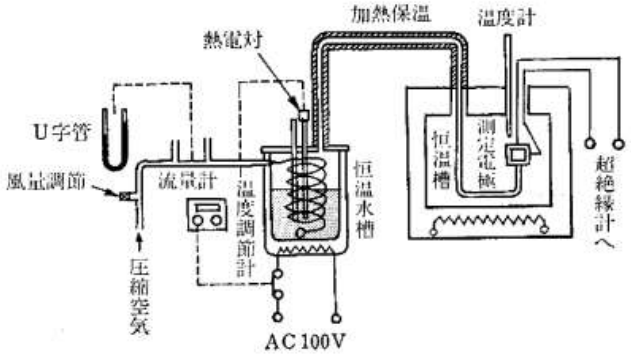
Different mixture of coal	Gas temp. (°C)	Apparent dust resistivity (Ωm)	Energization	Inlet dust concentration (g/m^3)	Outlet dust concentration (g/m^3)	Power consumption (kWh)
A	120	$9.4 * 10^9$	DC	13.3	30	8.5
B	123	$1.5 * 10^{10}$	DC	16.2	80	6.2
C	124	$2.5 * 10^{10}$	DC	20.5	147	4.5

Moving belt-type ESP

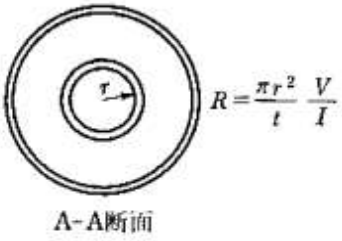


Dust deposition is constantly scraped off to avoid back corona.

Measurement method of Apparent dust resistivity (JIS 9910)

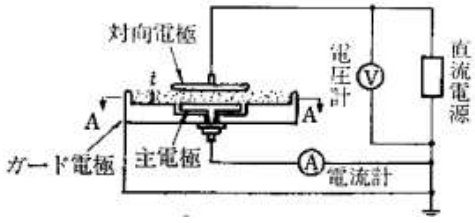


Use of a chamber with constant temperature and humidity



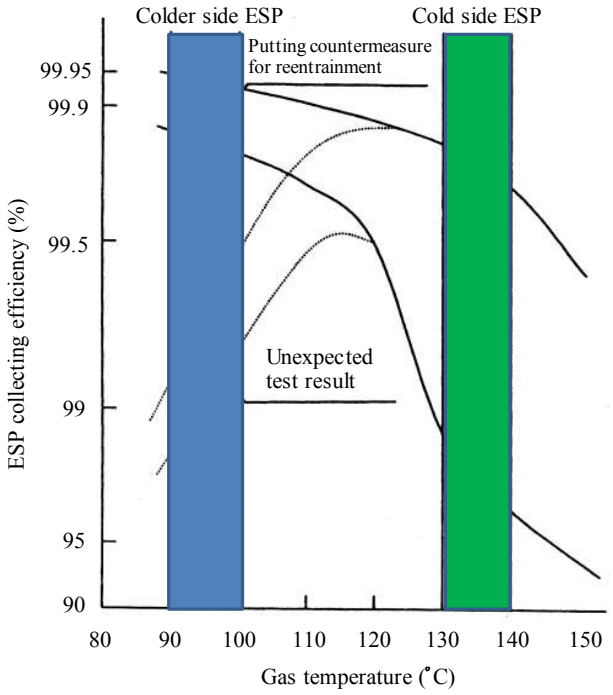
$$R = \frac{\pi r^2}{t} \frac{V}{I}$$

Electrode



Measuring circuit

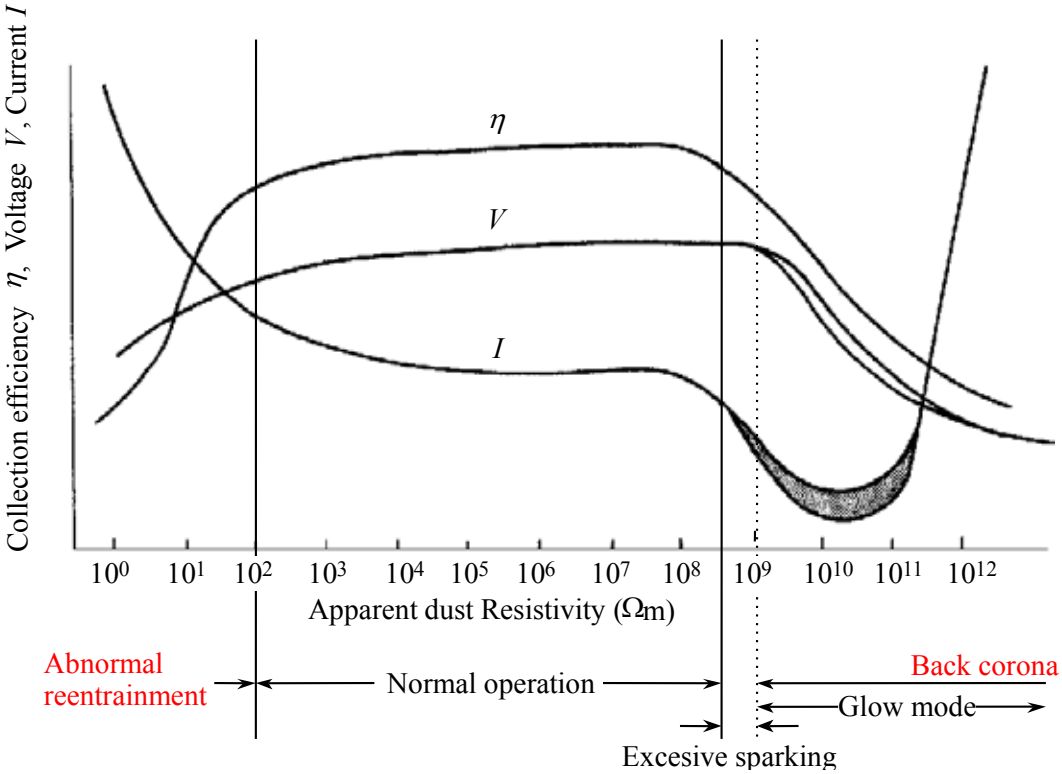
Gas temperature vs. collection efficiency



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

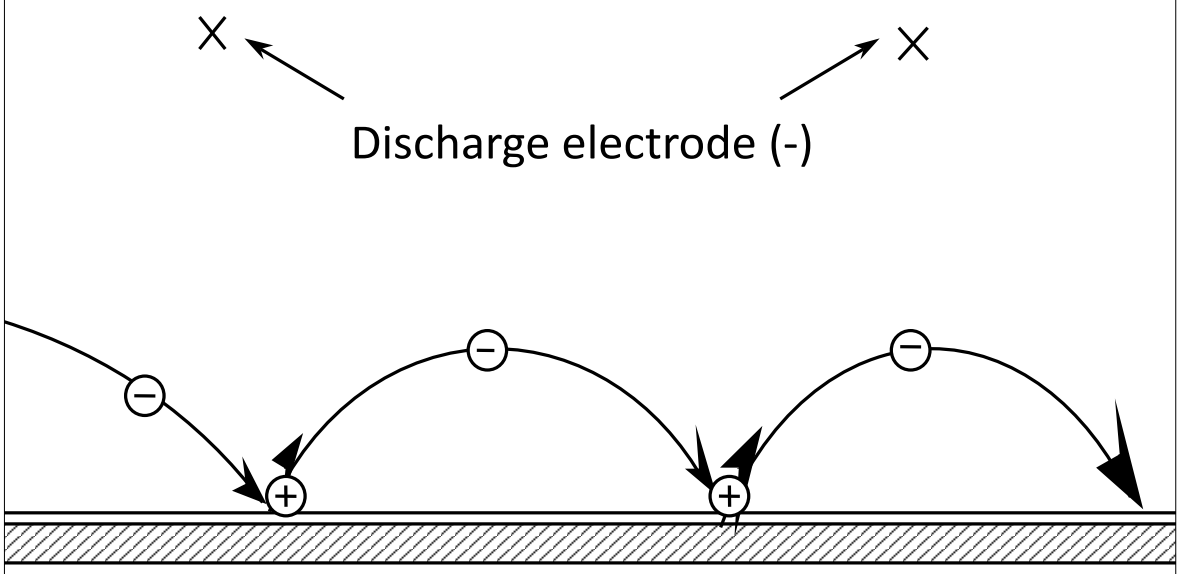
Blending different kind of coal is also effective to avoid back corona.

Effect of apparent dust resistivity on collection efficiency



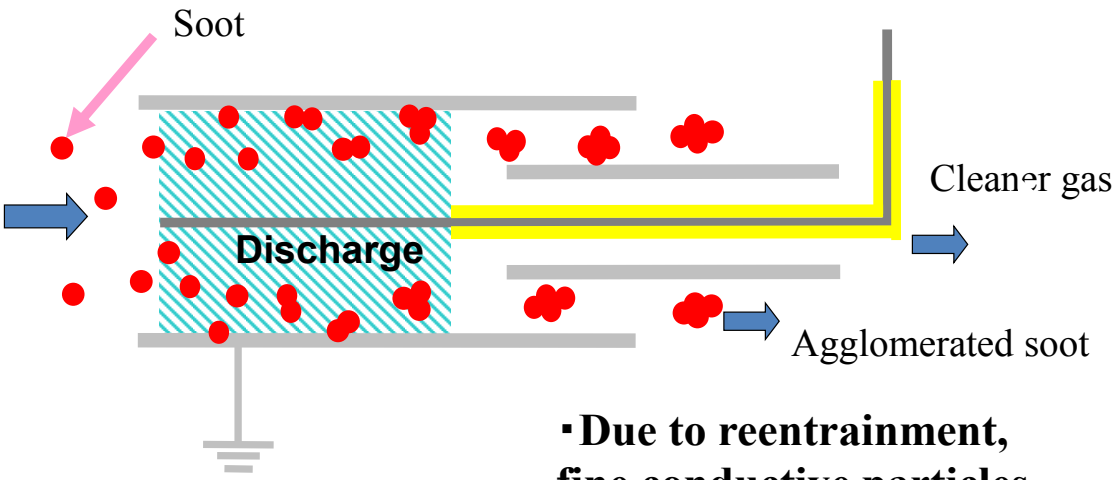
Abnormal Dust Re-entrainment

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



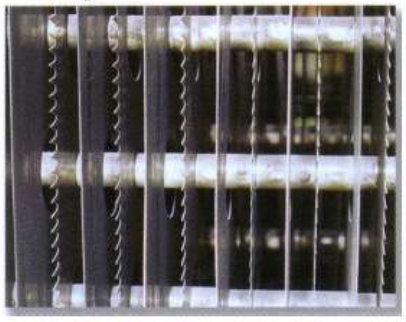
Diesel Soot Agglomeration

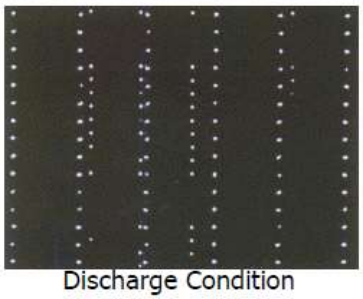
(Utilization of abnormal reentrainment)



▪Due to reentrainment, fine conductive particles become large

Features of Electrode System of Tunnel ESP





Discharge Condition

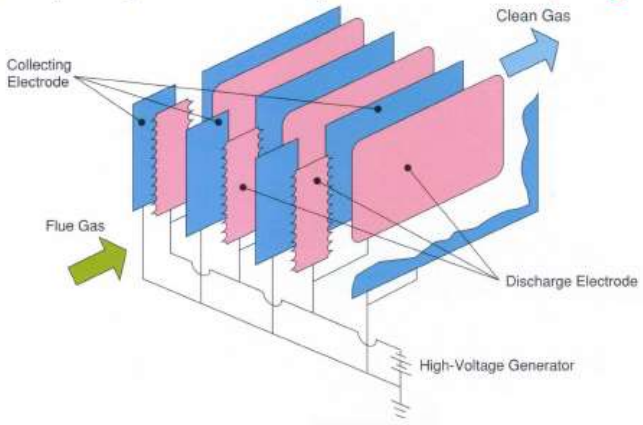
Very fine diesel particulate shall be removed.

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)

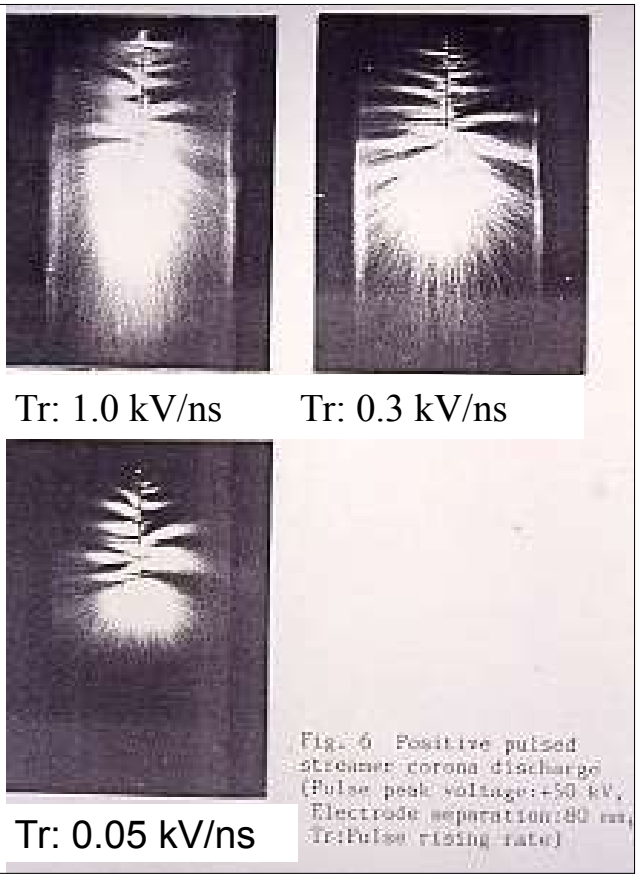
⇨ Specially designed electrode system with narrow spacing



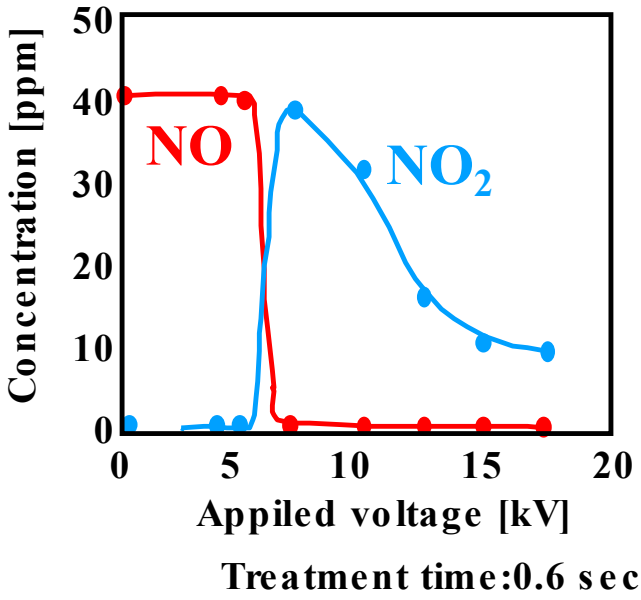
MHI Co. Ltd

Positive pulsed discharge in needle-plate electrode

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



Oxidation of NO in air with pulsed streamer discharge



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)

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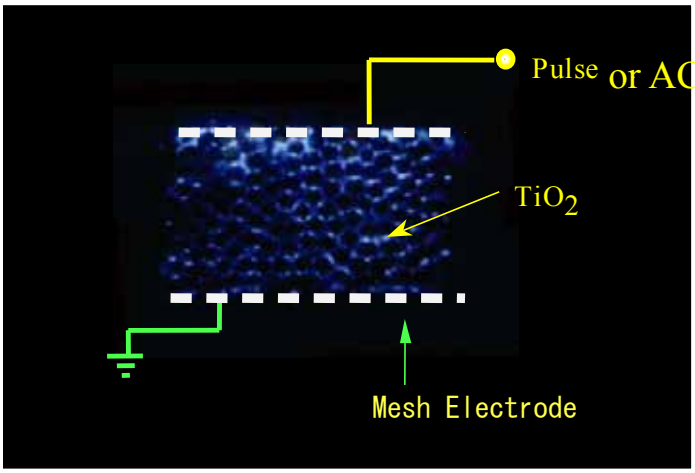
Packed bed with TiO_2 pellets



Packed-Bed Type Reactor

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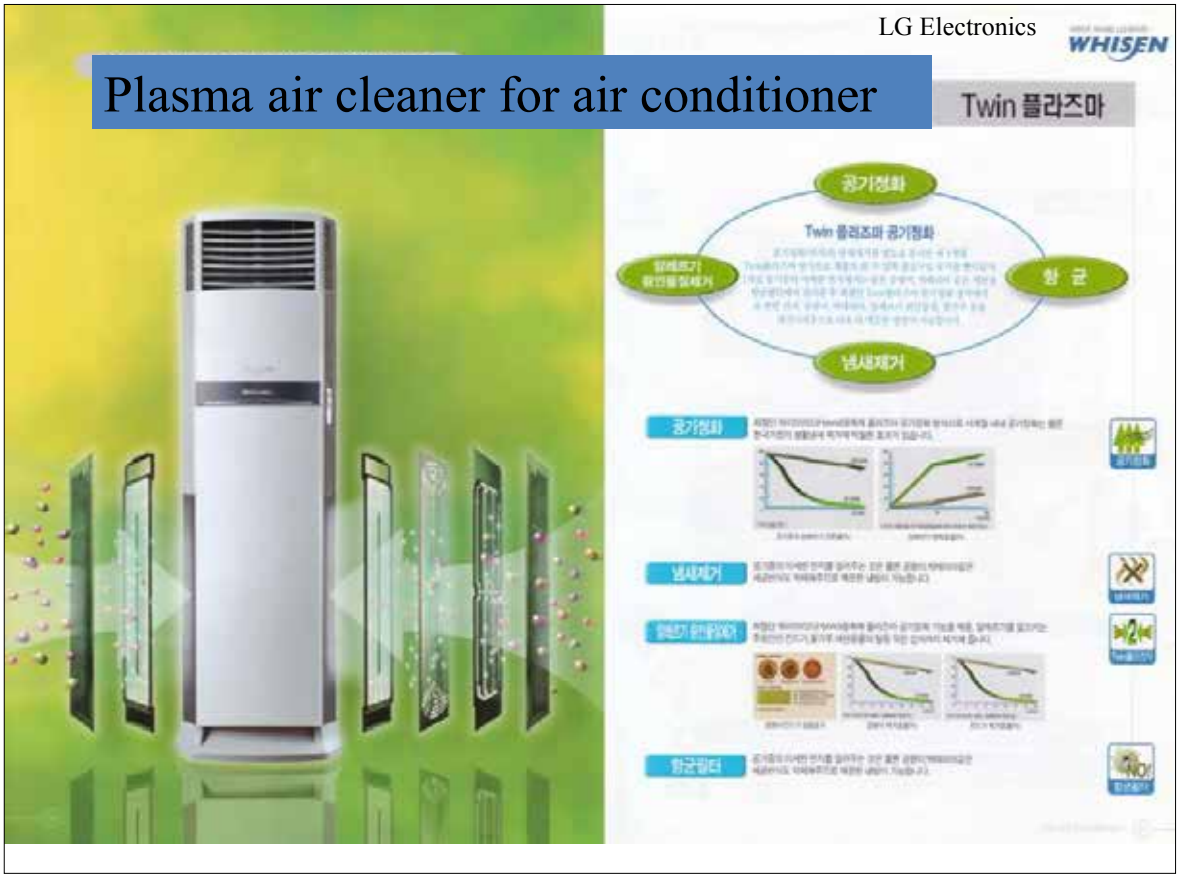
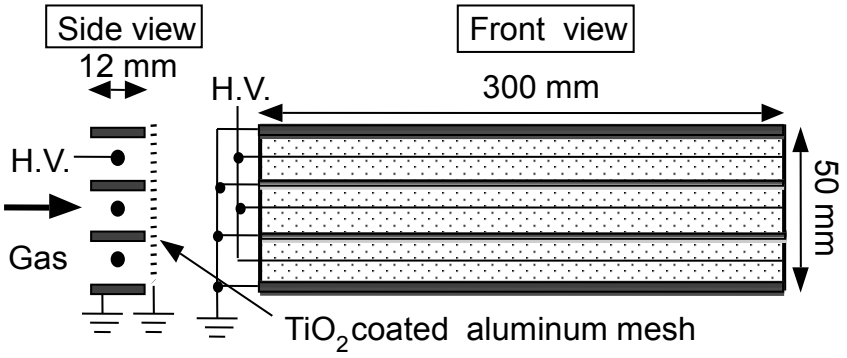
LG Electronics

WHISEN

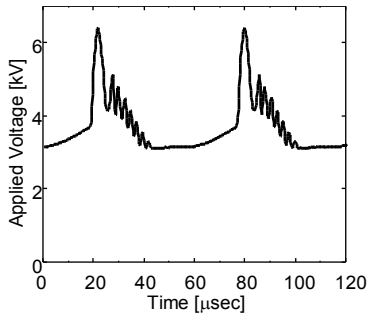
Plasma air cleaner for air conditioner



Plasma reactor combined with TiO_2 photocatalyst



(a) Setup of plasma reactor combined with TiO2



(b) Waveform of pulse voltage

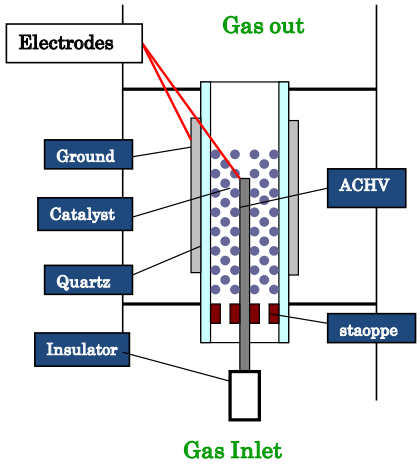
Pulse is superimposed to dc voltage

Amano Co., Ltd

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

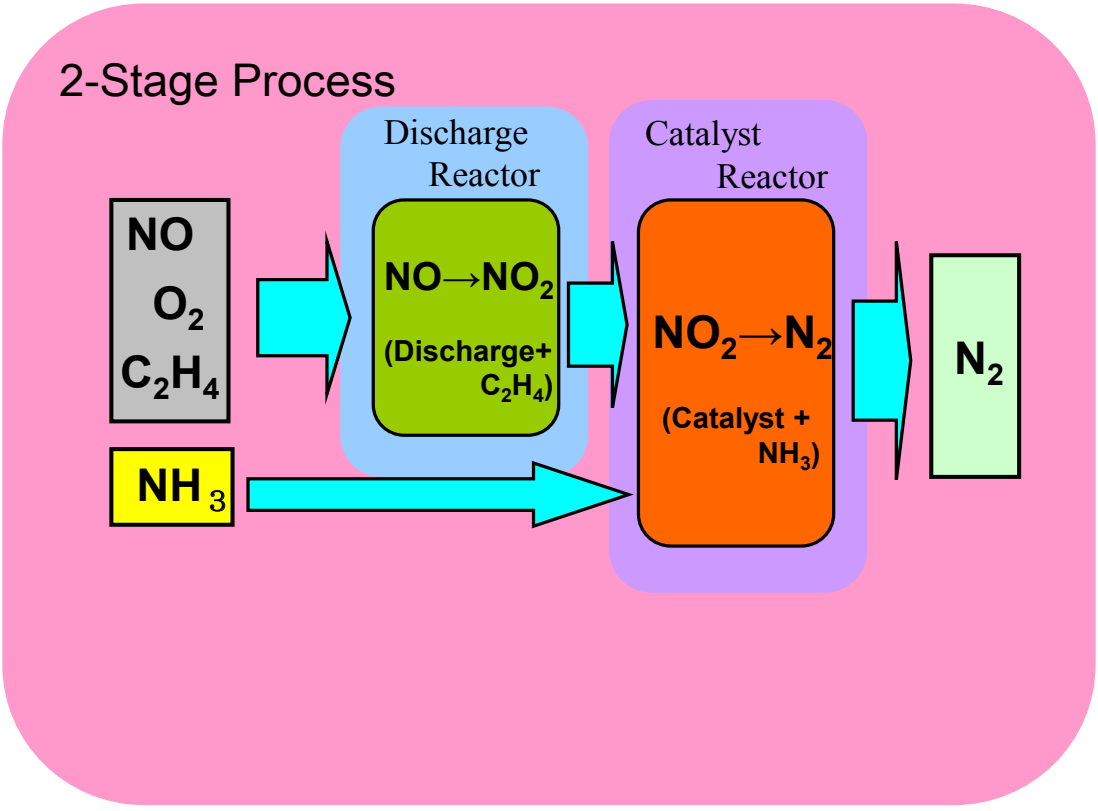


- 30 kHz AC high voltage
  Vp-p: 10 kV
- Pt Catalyst + Plasma
- Heating by plasma

Plasma-assisted combustion

Operating temperature: 200 - 400 C

Typically 2000 ppm of Toluen can be completely oxidized to CO2 and H2O with 10 ms detention time in the plasma section

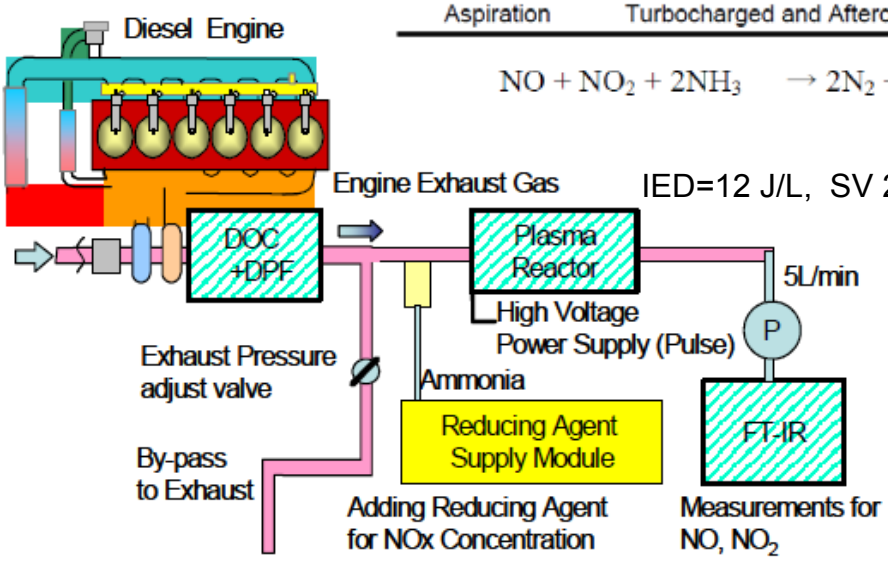


DeNOx for Diesel exhaust using Test bench with JE05 mode (Sato, et al. SAE 2011)

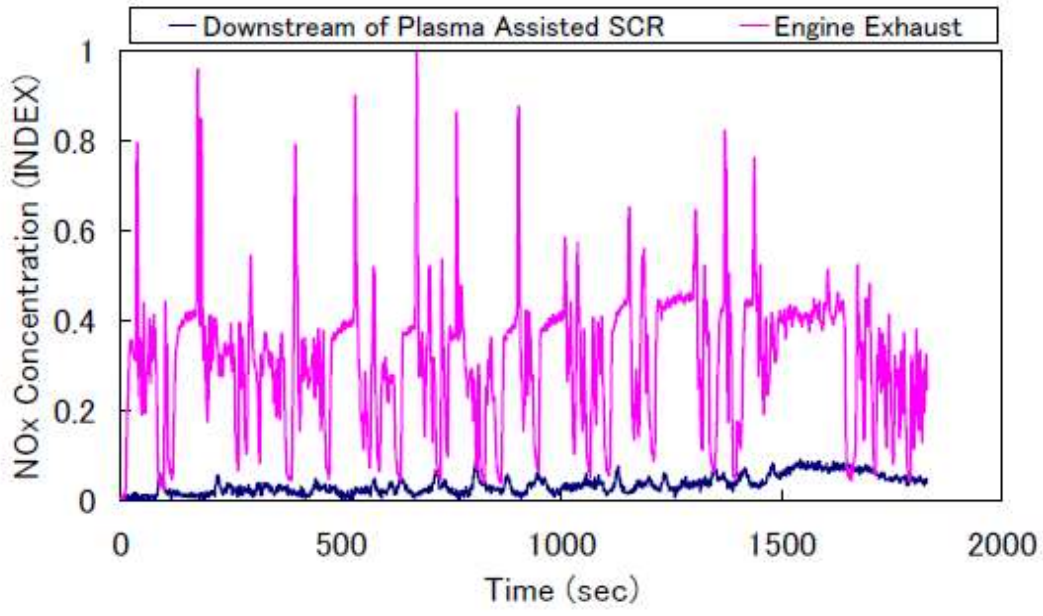
Table .1 Specifications of Test Engine

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

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



(Background slide 2)
Comparison of the Instantaneous NOx Concentration at Inlet and at Outlet of the Plasma Reactor (Sato, et al. SAE 2011)

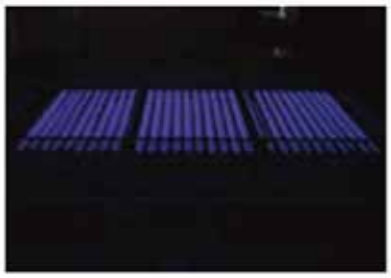


Air cleaning apparatus for smoking room

(Nittetsu Mining Co., Ltd)

Particle, odor, and CO removal

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



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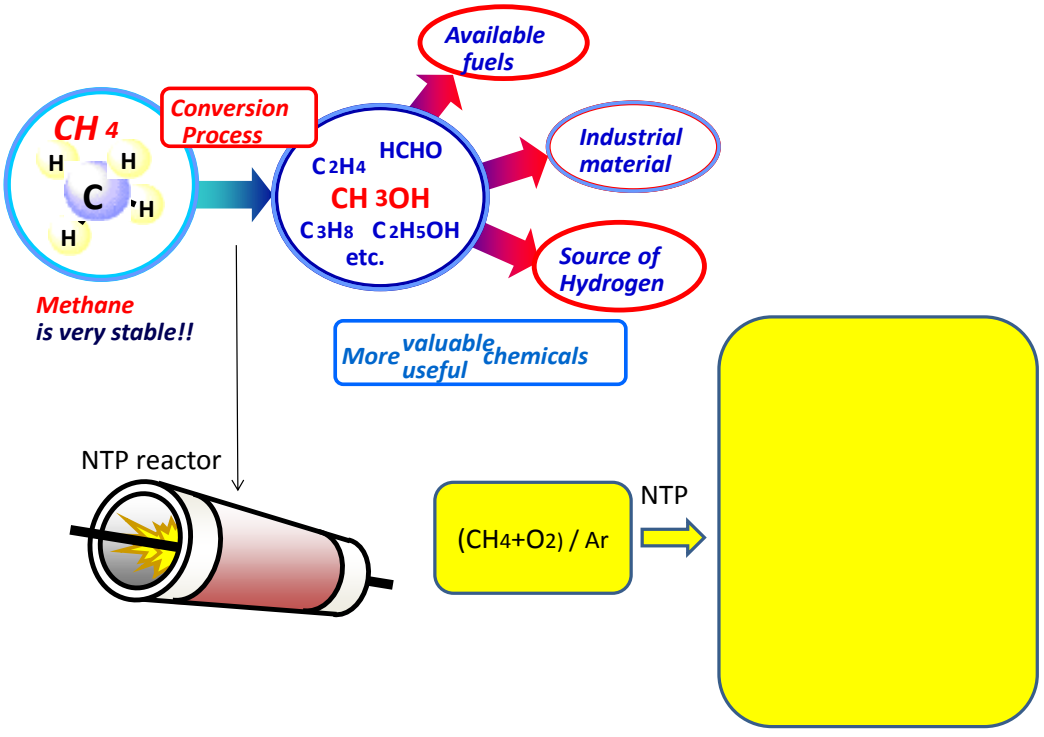
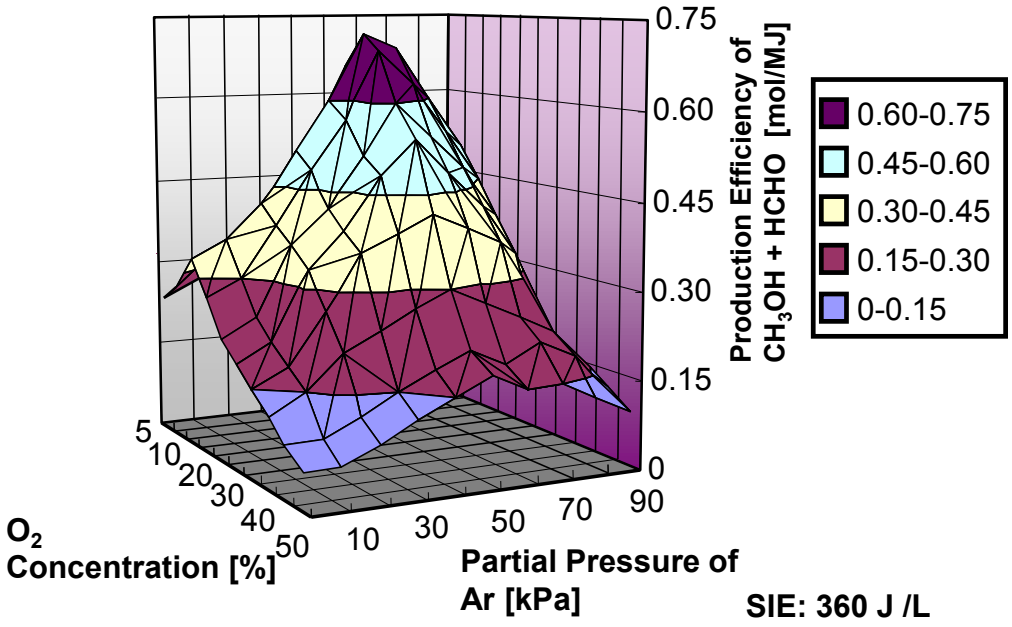
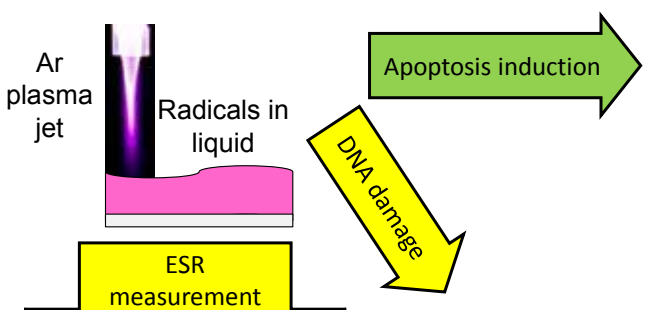
Conversion of METHANE by NTP

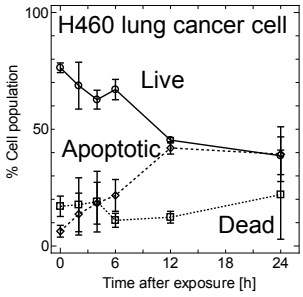


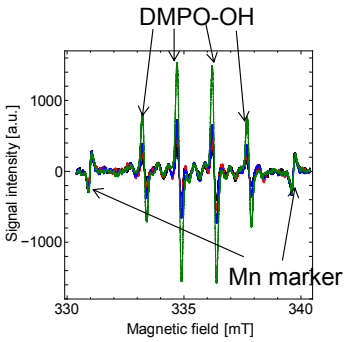
Production efficiency of methanol vs. Oxigen concentration and Ar partial pressure



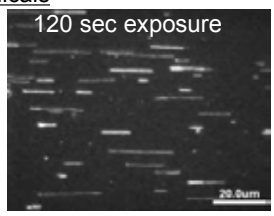
Biological Applications (Sterilization, Surface modification, Plasma medicine, etc.)





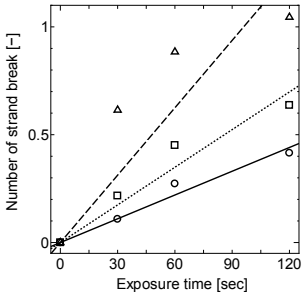


DNA fragmentation method for quantify the reactivity of radicals



(Single-molecule DNA imaging)

Number of strand breaks



H. Kurita, *et al.*, *Appl. Phys. Lett.*, **99**, 191504 (3 pp.), 2011 52

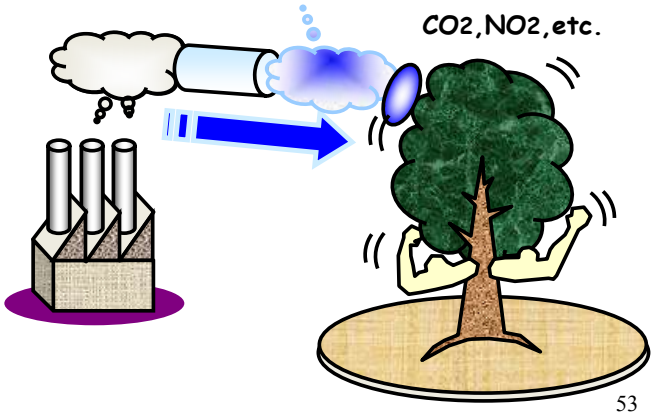
ICPM-5: 19-P02-06, 20-BO08

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.



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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.

Note

Note

Note

Note

Note

2019 글로벌 기계기술 포럼

2019 GLOBAL FORUM ON MECHANICAL ENGINEERING

SESSION 2

미세먼지 저감 기계기술

Mechanical Engineering for Reducing Fine particles

SESSION 2

미세먼지 저감 기계기술

배출가스 저감과 내연 기관의 미래

Emissions and Immissions – The Diesel Perspective
An Assessment of the Future of Internal Combustion Engines

>> 독일 칼스루헤 공과대(KIT) Thomas Koch 교수
자동차동력기관연구소장

Thomas Koch / Professor, Karlsruhe Institute of Technology
Germany

Emissions and Immissions – The Diesel Perspective

An assessment of the Future of Internal Combustion Engines

Thomas Koch

Professor/Director

Internal Combustion Engine Research Institute (IFKM)

Karlsruhe Institute of Technology

Fine Dust / PM

Floating particles in the atmosphere are called fine dust or Particulate Matter (PM). Depending on their size and composition they can have a impact on the physical health. Due to this characteristic there are legal limits in Europe for PM10 in the atmosphere since 2005. These limits were tightened in the last years. The current gravimetric limit is defined 40 µg/m³.

The largest anthropogenic sources for fine dust in Germany are the industry, traffic, private households, heating stations and agriculture. One part of this list is the combustion engine. Particles or the combination of particles as soot are one component of the exhaust gas of combustion engines. Due to fuel rich parts in the combustion zone, which is characteristic for diesel engines, particle formation is unavoidable. Diesel particulate filters significantly reduce the particulate concentration, which enables an ongoing improvement of the aftertreatment technic bringing the emission rate to a minimum.

The limits for particle concentration in the atmosphere must be compliant close to highly frequented roads as well. Measurement stations are placed at specific hot spots for monitoring. Since 2005 the days with too high particle concentrations are limited for every spot to 35 days per annum. "Stuttgart-Neckartor" is best known monitoring station in Germany and an excellent example due to one of the highest rates of exceedance days in former times (see figure 3 and 4).

Figure 1 shows the exceedance days for "Stuttgart-Neckartor". The year 2005 got 187 days with higher particle concentration than 50 µg/m³. This was 152 days more than the limit of 35 days a year. After 2005 up to 2018 the numbers of exceedance days were continuously decreasing until 2018 with only 21 days in 2018 year and therefore 14 days below the annual limit.

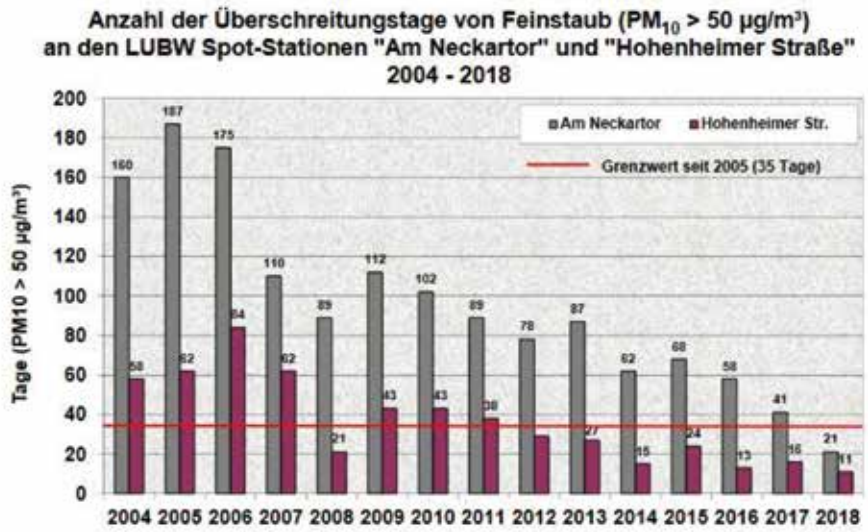

Figure 1: Exceedance days of the PM10-limit of 50 µg/m³ for "Stuttgart- Neckartor" (grey), and "Hohenheimer Str" (dark red). The exceedance days limit is 35 days a year (red horizontal line). Source: LUBW, Grafik: AfU Stuttgart, Abt. 36-4

Figure 2 shows the yearly averages of the PM10 particle concentration at "Stuttgart-Neckator" for the last 15 years. The years 2004 to 2006 showed a higher concentration than 50 µg/m³. The limit was set to 40 µg/m³. After 2006 the annual averages were decreasing and for every year since 2011 not higher than the limit and still dropping.

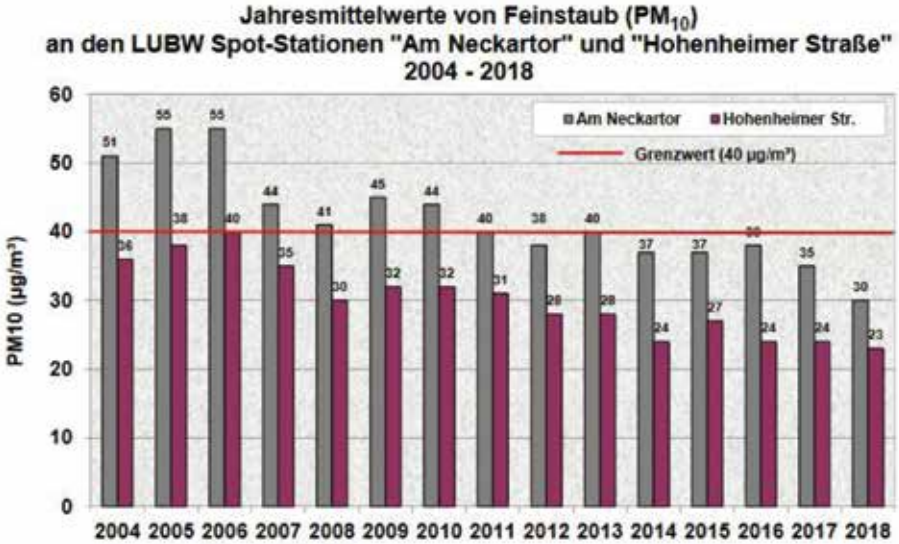

Figure 2: Annual average of the PM10 for "Stuttgart- Neckartor" (grey), and "Hohenheimer Str" (dark red). The PM10 limit is 40 µg/m³ (red horizontal line). Source: LUBW, Grafik: AfU Stuttgart, Abt. 36-4

Over the last 15 years a reduction of the exceedance days of 89% and the annual average of the particle concentration of 45% at the "Neckartor" was achieved and all values are below the limits. The next years a further decrease of PM10 imissions is expected due to the ongoing replacement of vehicles with older exhaust aftertreatment technic by Euro 6d vehicles. The diesel particulate filter has been introduced for all passenger car diesel vehicles in 2009.

The overall situation of the fine dust in Germany is shown in figure 3 and figure 4. The colored sections indicate the amount of days of exceedance with a limit of 50 µg/m³ for the daily average. All the blue areas are below 35 days. The dots spread throughout the map are measurement stations very close to traffic spots. In the year 2014 (figure 3) we had light and dark blue zones (below the limit) nationwide and only few spots with exceedance days of 35 to 49 (yellow color). Only one measurement station in Germany at "Stuttgart-Neckartor" counts more than 56 exceedance days. Only two years later in 2016 (figure 4) every area stay below the limit except the station at "Stuttgart-Neckartor".

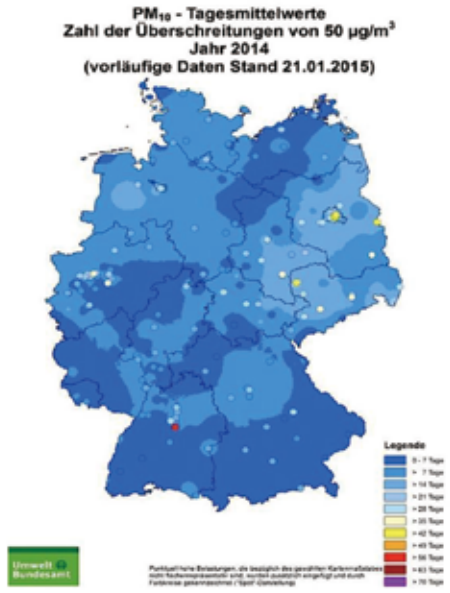

Figure 3: Number of exceedance days for PM10 in Germany with a daily average limit of 50 µg/m³ in the year 2014. Source: German Federal Office for Environment

Figure 4: Number of exceedance days for PM10 in Germany with a daily average limit of 50 µg/m³ in the year 2016. Source: German Federal Office for Environment

The sources for fine dust at traffic spots can be split in two sections: first the local load, caused by traffic on that road and nearby buildings, and second the background level with all the sources from the wider environment. Figure 5 shows the proportions for the single sources. The exhaust of combustion engines as PM10 source has a share of 7% overall, 6% as local load and 1% as part of the totalbackground level. This fact therefore shows that combustion engines/Diesel contribution to fine particulate matter is negligible.

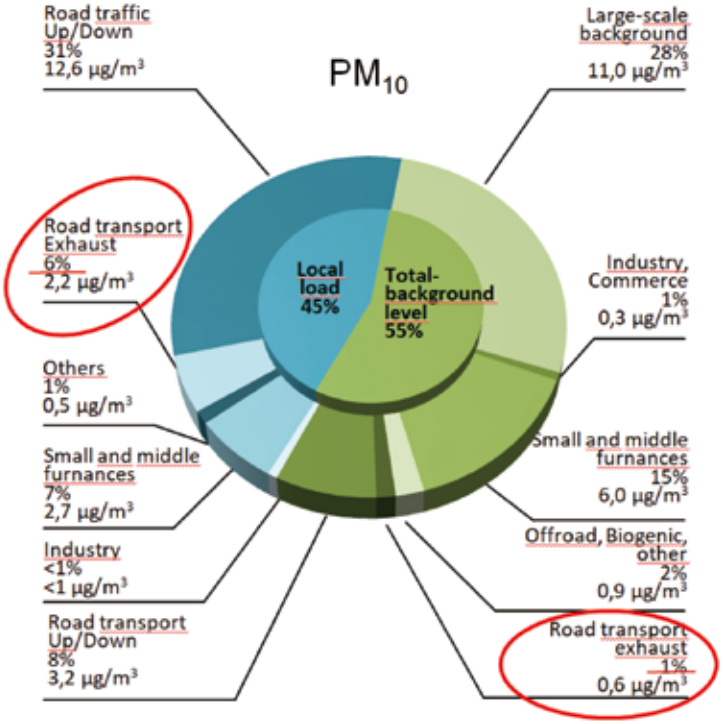

Figure 5: Shows the proportions of the PM10 sources at traffic spots. Source: Christoph Erdmenger; Ministerium für Transport und Infrastruktur Baden Württemberg; IFKM/KIT – NO_X Conference, Heidelberg, 01.2016

NO_x

Nitrogen oxides (NOx) are gases with harmful properties for the respiratory organs and their output must be minimized. Since 2010 the annual emissions of NO_x in Germany are limited. In opposition to PM immissions, Diesel engines are the main cause of the NO2-Situation.

Again the measurement station "Stuttgart-Neckartor" is a good example for the evaluation of the NO_2-immission situation in Germany as highest values in Germany had been detected here. Figure 6 is a map of the periphery of "Stuttgart Neckartor" measurement station and the colored dots show the NO_2 concentration of spots next to the roads in this area. The position of the measuring station (red square) is at the hotspot.

Figure 7 shows the profile crossing, the street and the building (grey square) of the area around the measurement station of "Stuttgart-Neckartor" and the colored parts depict the annual average of the NO_x concentration in this atmosphere. The highest values (red area) are directly around the road (black lines) mainly caused by internal combustion engines of the vehicles. The values of the measuring station indicate that the position of this station is very close to this road. The figure also depicts that the building next to the road blocks the wind to carry the NOx away from the hotspot, which causes increased local concentrations. Sections around this spot only a few meters away from the road reveal much lower values of the NO_2 concentration.

Figure 6: Map in the periphery of "Stuttgart-Neckartor" depicting the NO_2 concentractions (colored dots) next to the roads. The red square shows the position of the measuring station. Source: Vogt et. al. Universität Stuttgart, 25. ALS-Kolloquium „Stickstoffoxide und Feintsaub in Städten"

Figure 8 shows the exceedance hours per annum since 2004 with a limit of 200 µg/m³ NO_x in the atmosphere. The annual limit for exceedence hours had been 175 hours until 2009 and was reduced to 18 hours in 2010. In 2005 and 2006 the measurement station "Am Neckartor" counts over 800 exceedance hours. Since then the values dropped by about 99 percent until 2018. Since 2017 the annual exceedance hours are below the limit of 18 hours.

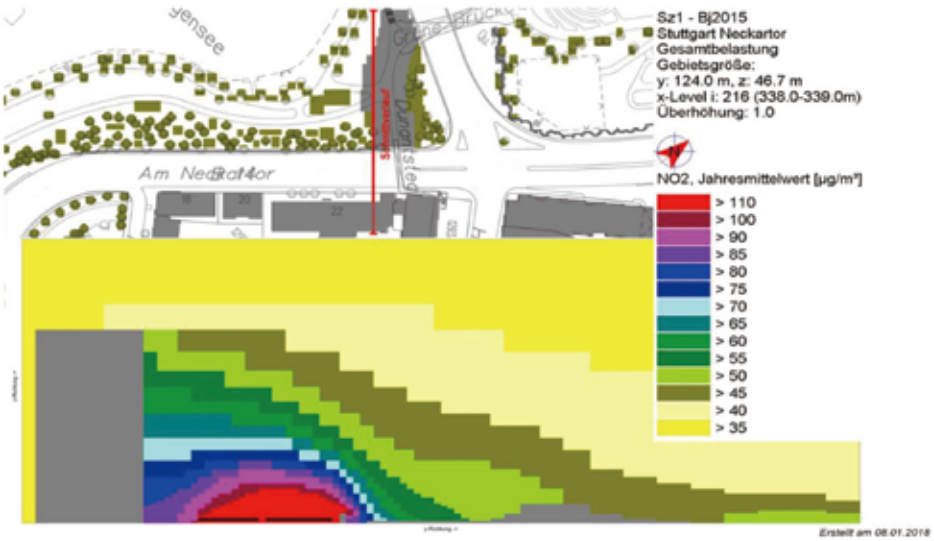

Figure 7: Sectional view of the yearly average NO_2 immissions shown in a profile of the area around the measurement station "Stuttgart-Neckartor". Source: Aviso GmbH

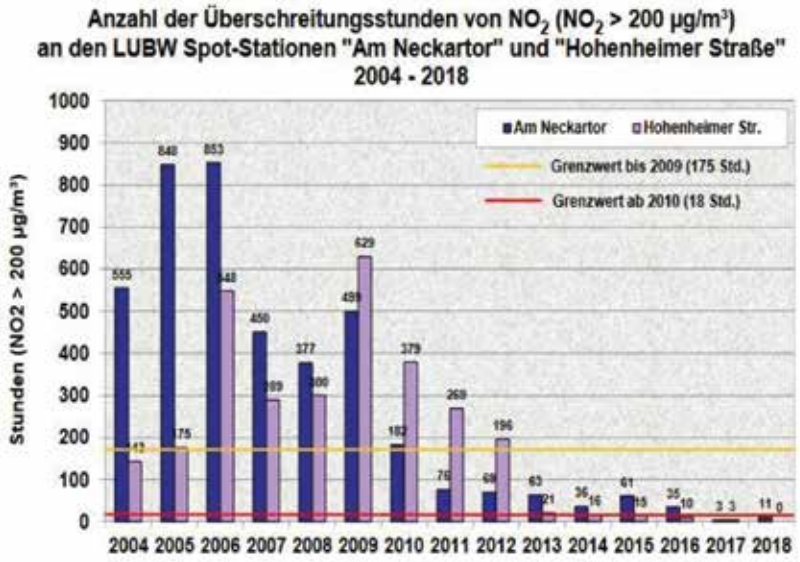

Figure 8: Exceedance hours of the NO_2-limit of 200 µg/m³ for "Stuttgart- Neckartor" (grey), and "Hohenheimer Str." (dark red). The exceedance hour limit was 175h a year (yellow horizontal line) and is 18h a year since 2010 (red horizontal line). Source: LUBW, Grafik: AfU Stuttgart, Abt. 36-4

The yearly average of NO2 concentration in the air is limited to 40 µg/m³ nationwide. Figure 9 shows the values for the annual average at "Stuttgart-Neckartor" from 2004 to 2018. Since 2006 with the highest concentration of 121 µg/m³ the value has been decreasing continuously by about 40 percent. However even in 2018 the yearly average of NO_2 immission at this spot is still not low enough to meet the requested limit.

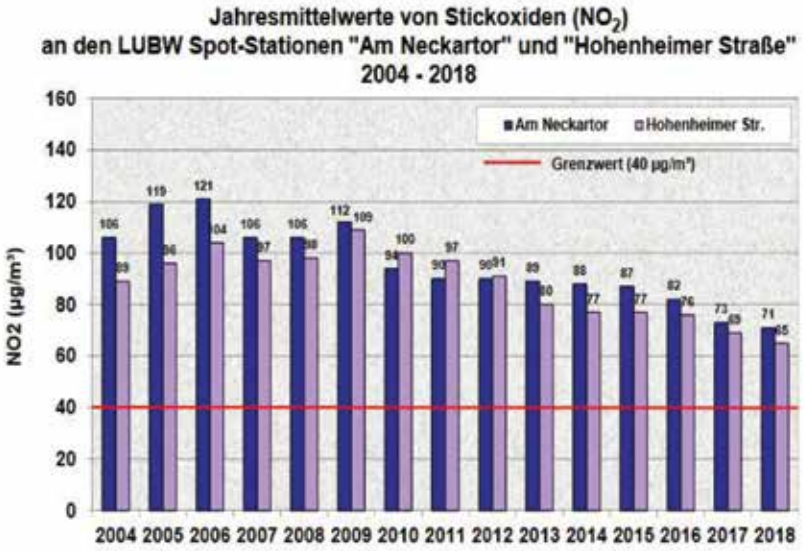

Figure 9: Annual average of the NO2 for "Stuttgart- Neckartor" (grey), and "Hohenheimer Str" (dark red). The NO_x limit is 40 µg/m³ (red horizontal line). Source: LUBW, Grafik: AfU Stuttgart, Abt.36-4

The increased NO_2-immission values led to stricter emission limits for combustion engines. The exhaust aftertreatment systems for current newly registered vehicles have been improved. Recent studies show that Euro 6d Diesels typically meet the limit of 80 mg/km and even stay far below the critical value (see figure 10). That points out the further decreasing of NO_2 immissions in the next years.

Diesel-Pkw:

Modell	Abgas-norm	Mess-temperatur	RDE: NO_x in mg/km
Audi A8 50 TDI	6c	23,4° C	15
BMW 520d Steptronic	6c	14,0° C	5
BMW 520d Touring	6d-TEMP	5,4° C	1
BMW X2 xDrive 20d	6d-TEMP	6,8° C	23
Citroen Berlingo BlueHDI 130	6d-TEMP	5,8° C	7
Honda Civic 1.6 i-DTEC	6d-TEMP	24,9° C	101
Kia Ceed 1.6 CRDi	6d-TEMP	18,8° C	22
Mercedes A 180 d	6d-TEMP	1,2° C	40
Mercedes C 220 d	6d-TEMP	19,5° C	0
Opel Astra 1.6 D	6d-TEMP	3,3° C	1
Peugeot 308 SW BlueHDi 180	6d-TEMP	13,3° C	30
Volvo XC60 D5 AWD	6d-TEMP	7,9° C	56
VW Golf 1.6 TDI SCR	6d-TEMP	-0,4° C	14

Figure 10: NO_x-values of a RDE-study of Euro 6 Diesel-passenger cars of different manufacturers. Source: ADAC

Exposition /Measures

The debate about pollutant thresholds is equivalent to a never ending story. The federal government of Germany was seeking scientific advice from experts in Halle*. The study of the national academy of Science Leopoldina came to the solution that a further reduction of NO_2 immissions is always appreciated but stricter legal limits for human health are not recommended**.

Not only the limits at all need to be discussed, but also the measurement method. It is obvious that pollutant concentrations around the roads depend on the distance to the exhaust source and the air circulations in this environment. Figure 12 shows NO_2-values close to a highly frequented road in Reutlingen. The immission concentration significantly depends on the distance to the road. It is obvious, that the measurement position has a strong impact on the measured results. Unfortunately there is no recommendation for the distance of the measuring station to the road in Germany, but a maximum distance of 10 meters (figure 11). This leads to close measurement distances. In opposite to Germany there is a recommendation in the USA within 20 meters and the maximum distance is 50 meters.

	Distance of measurement station form road		High		Source
	Empfehlung	max.	min.	max.	
Deutschland	-	10 m	1,5 m	4 m	39. BImSchV
USA	Innerhalb 20 m	50 m	2 m	7 m	EPA Technical Document

Figure 11: Comparison of parameters of the positioning of traffic-related measurement stations

*Source: https://www.mdr.de/nachrichten/politik/inland/schadstoff-grenzwerte-leopoldina-100.html
**Source: Nationale Akademie der Wissenschaften Leopoldina (2019): Saubere Luft. Stickstoffoxide und Feinstaub in der Atemluft: Grundlagen und Empfehlungen. Halle (Saale).

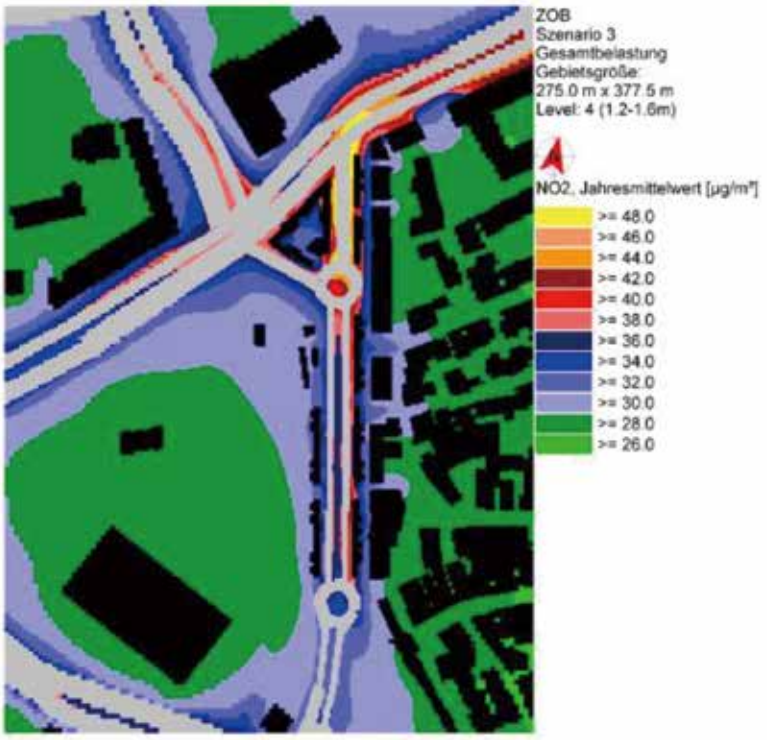

Figure 12: NO_2-values on a high traffic road. Colored sections show the annual average of NO2 immissions. Source: Aviso GmbH

As a result of this complex discussion it is clear, that even today the internal combustion engine technology contributes to the immissions inside cities. Nevertheless there is a strong decay and with most modern engine technology the immission impact of internal combustion engines can be neglected.

Note

Note

Note

Note

SESSION 2

미세먼지 저감 기계기술

석탄화력발전 미세먼지 저감 기술

Emission of Fine Dust From Coal–Fired Power Plants, and Doosan's Fine Dust Reduction Technology

>> 두산중공업 송시홍 전략/혁신부문Plant기술개발센터장

Si Hong Song / Vice President, Doosan Heavy Industries & Construction Korea

Doosan Heavy Industries & Construction

석탄화력발전 미세먼지 저감 기술

2019년 9월
두산중공업 기술연구원
송 시 홍 상무

본 문서는 두산중공업의 정보자산으로, 승인을 받지 않은 문서의 열람, 수정, 배포, 복사를 금지합니다.
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2 미세먼지 배출 현황

3 두산중공업의 미세먼지 대응 기술

- 탈질 기술 (DeNOx)
- 탈황 기술 (DeDust)
- 탈진 기술 (DeSOx)

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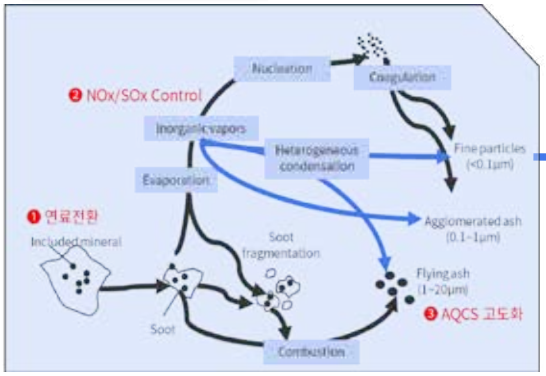
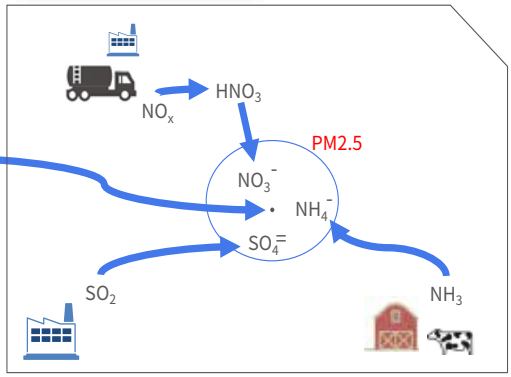
미세먼지 발생 메커니즘

- 먼지: 대기 중 더다니거나 흩날려 내려오는 입자상 물질
- **총먼지(TSP, Total Suspended Particles): 50 μm 이하**
- **미세먼지(PM10): 지름이 10 μm 이하 먼지 → 부유먼지**
- **초미세먼지(PM2.5): 지름이 2.5 μm 이하 먼지 → 미세먼지**

1차 발생



2차 발생



→ 미세먼지 1차 생성은 고체 연료(석탄)의 연소과정에 의해 생성되며, 환경부 발표 자료에 따르면 2차 미세먼지 생성은 발생된 NOx(7%), SOx(24.5%)가 전구물질(Precursor) 역할을 하여 미세먼지를 생성에 기여함.

미세먼지 배출 현황

석탄발전이 초미세먼지에 미치는 기여도는 11~14%로 추정되며, 직접 배출 외에 2차 생성을 방지하기 위해 NOx, SOx 저감 노력이 필요함

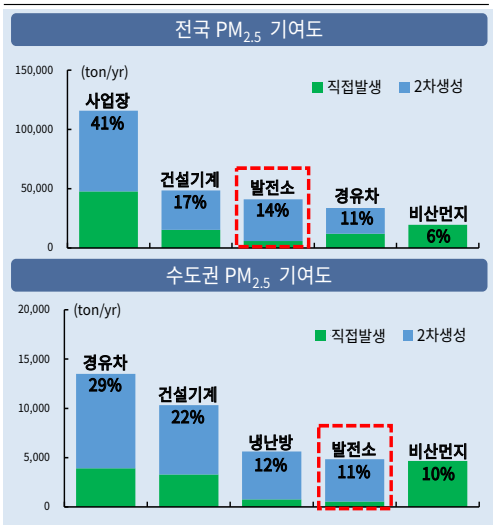
정의

- 미세먼지(PM_{10}) : 직경 10μm 이하 입자
- 초미세먼지($PM_{2.5}$) : 직경 2.5μm이하 입자

발생과정

- **직접 발생**
  - 자동차, 산업설비, 보일러 연소 등 입자배출
  - 응축성 가스(SO_3 등)
- **2차 생성**
  - $PM_{2.5}$ = NOx/SOx + 수증기, 오존, 암모니아 등
  - 직접발생의 1.2배 생성 추정

초미세먼지 석탄발전 총 배출 기여도[1]

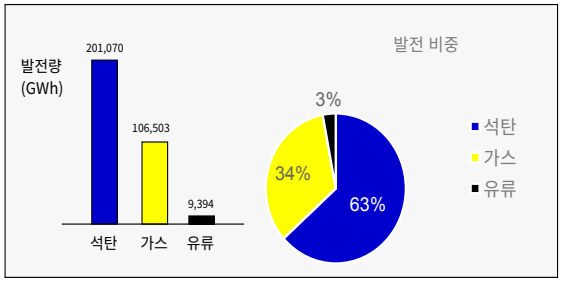


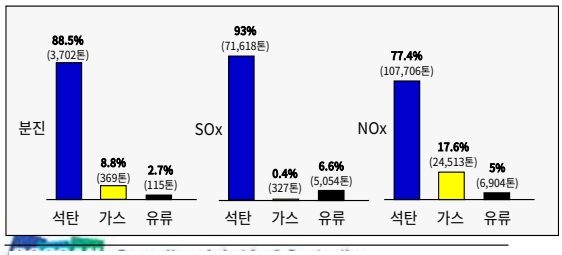
1. '13년 국가 대기오염물질 배출량, 국립환경과학원('15.12)

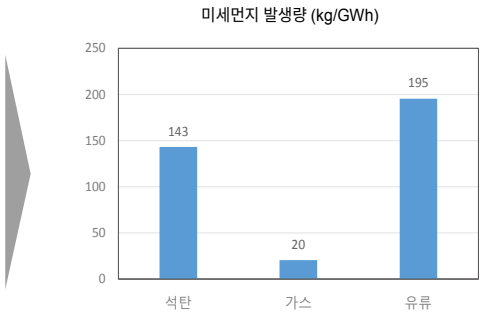
화력 발전원별 미세먼지 발생현황

국내 발전은 석탄화력이 63%, 가스 발전이 34% 이며 발전원별 미세먼지 발생량은 발전량이 가장 적은 유류가 가장 크고 석탄 화력 역시 가스의 7배 수준임

발전원별 미세먼지 배출량







출처: 미세먼지 관리 특별대책의 현황 및 개선과제(2016.10), 국회예산정책처, P72

Page 4

석탄화력 발전소 미세먼지 배출 저감 기술적 issue

석탄화력발전이 국내 주 발전원이고 미세먼지 배출 저감을 위해서는 미세먼지(PM10)을 제거 할 수 있는 기술과 2차 오염물질을 제거 설비의 고효율화가 필요하다.

오염 물질	현 설비	기술적 이슈 사항
➢TSP[1]/PM10[2]/ PM2.5[3]	Dry EP[4]	✓ 10um 보다 큰 먼지의 제거 효율 99.99% ✓ 추타 시 재비산으로 인해 PM10/PM2.5 제거 효율이 낮음
➢ NOx	T-firing 버너 SCR	✓ 표준화력 최신 low NOx T-firing 버너 개조 필요 ✓ 암모니아 slip ✓ 고효율화 (90 -> 95%)
➢ SOx	GGH WLFGD[5]	✓ 누설율 4~10% => 1% 이하 또는 무누설 필요 ✓ 고효율 (95->99%) FGD 필요

1. Total Suspended Particulate Matter
2. Particulate Matter less than 10 um
3. Particulate Matter less than 2.5 um
4. Electrostatic Precipitator
5. Wet Limestone FGD

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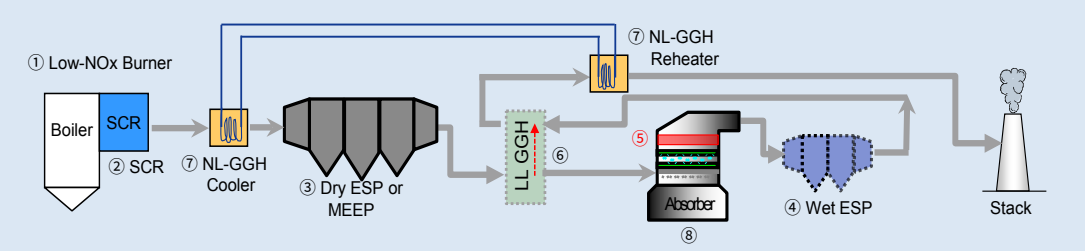
두산 중공업의 미세먼지 대응기술

석탄화력발전소 연소 후 가스 배출 단계별 가용 기술 배치도



	기술명	가용 Options	출구 농도
탈질 기술 (DeNOx)	① L-Burner	• 표준화력용 저 Nox 버너 개발, 대항 연소용 초저Nox 버너	• 100 ppm
	② SCR[1]	• SCR 촉매 추가 설치, Slip 방지를 위한 AAIG 개발	• 10 ppm
탈진 기술 (DeDust)	③ ESP/MEEP[2]	• 집진기 성능개선 : 집진 면적 증가 or 이동형 집진판 설치	• 10 ~ 4 mg/Nm^3
	④ Wet ESP	• 탈황설비 후단에 미세먼지 습식 집진기 설치	• 3 mg/Nm^3
	⑤ EME[3]	• 탈황설비 후단에 미세먼지 제거용 EME	• 1 mg/Nm^3
탈황 기술 (DeSOx)	⑥ LL-GGH[4]	• 가스-가스 열교환기 가스 누출율 개선	• 1%이하 누설
	⑦ NL-GGH[5]	• 기밀형 가스-가스 열교환기로 설비 개선	• 무 누설
	⑧ Absorber	• 습식탈황설비 성능개선 : Spray 노즐 개선, Tray 설치	• 10 ppm

1. Selective Catalytic Reduction
2. Electrostatics precipitator / Moving Electrode type Electrostatic Precipitator
3. Electrostatic Mist Eliminator
4. Low Leakage Gas-Gas Heater
5. Non Leakage Gas-Gas Heater

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두산 중공업 탈질 기술
Low-NOx 버너
SCR - AAIG

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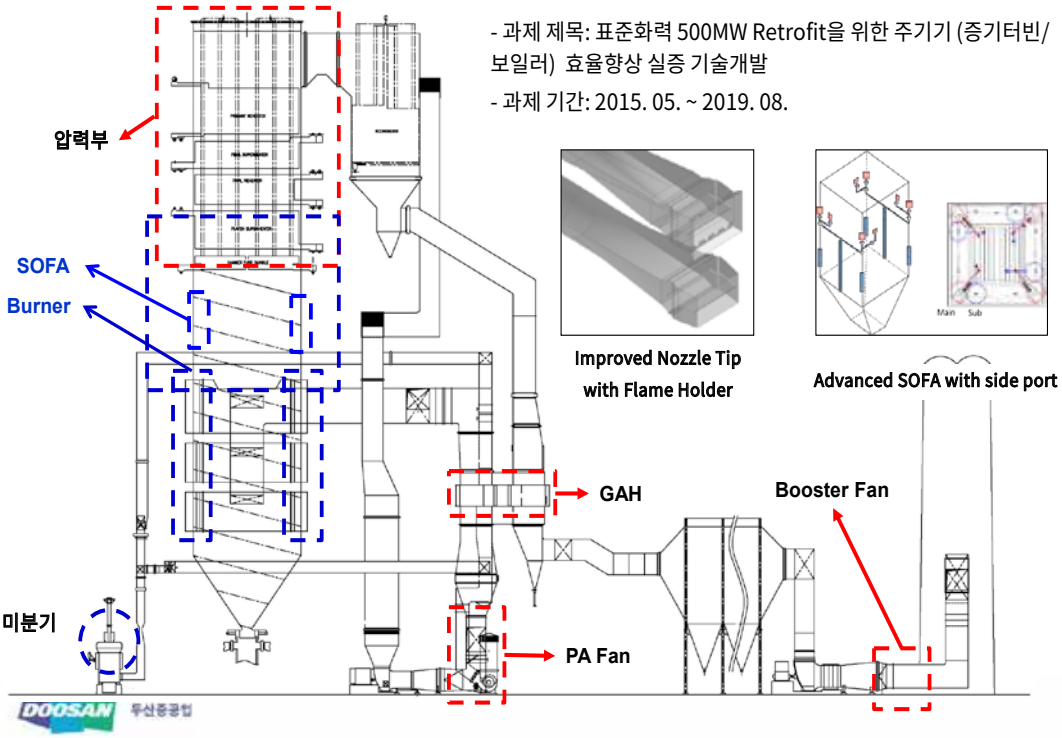
–7

T-firing Low NOx 연소 시스템 기술: 표준 화력 발전소 (1/2)

탈질 기술 (DeNOx)

- 과제 제목: 표준화력 500MW Retrofit을 위한 주기기 (증기터빈/보일러) 효율향상 실증 기술개발
- 과제 기간: 2015. 05. ~ 2019. 08.

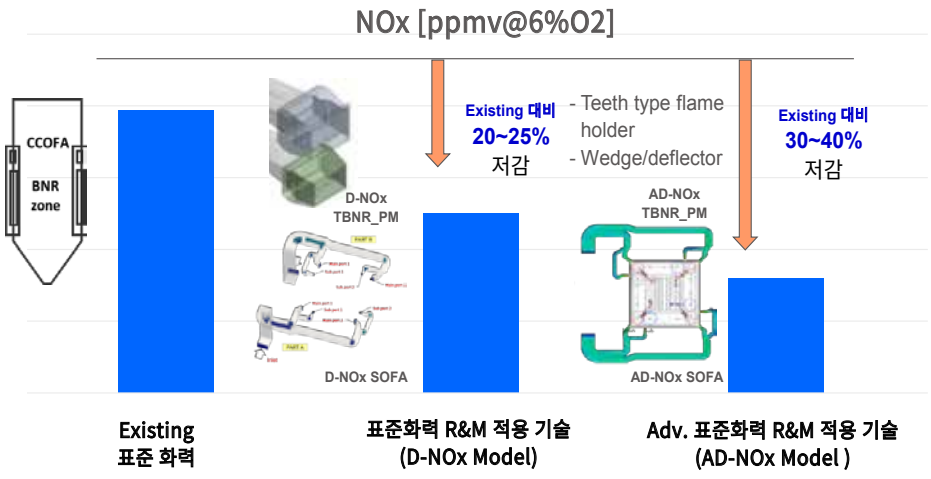


DOOSAN 두산중공업

T-firing Low NOx 연소 시스템 기술: 표준 화력 발전소 (2/2)

탈질 기술 (DeNOx)

시장의 환경과 정부의 정책에 따른 반영으로 표준 화력 대상으로 저 NOx 연소 시스템을 개발하였고 표준 화력 R&M 사업에 NOx 저감을 위하여 저 NOx 연소 Solution (D-NOx, AD-NOx Models) 제공 가능함.

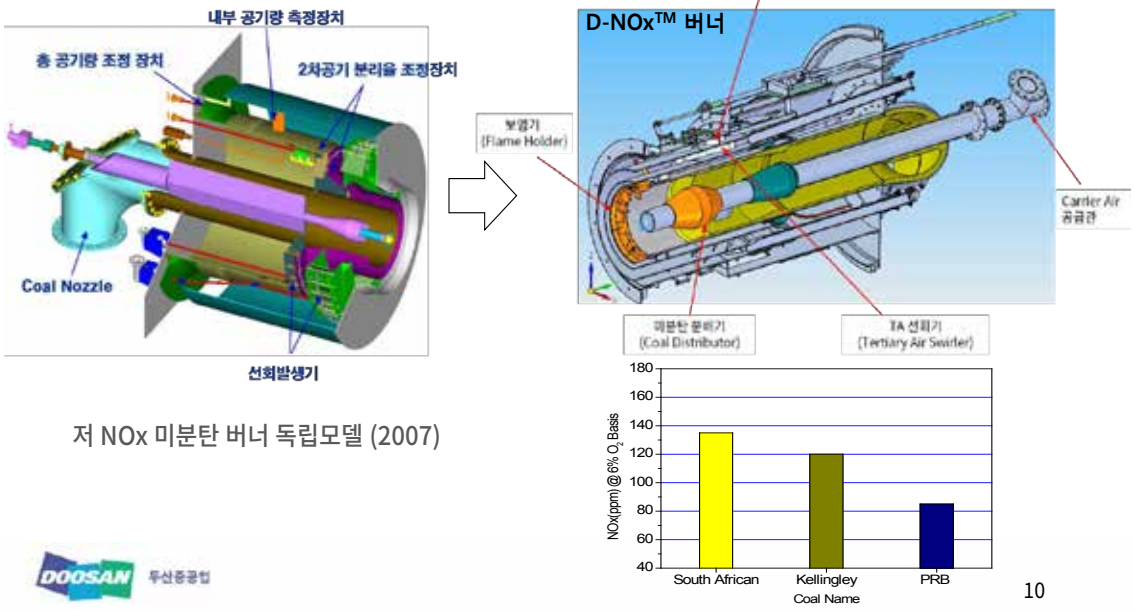


DOOSAN 두산중공업

Wall firing - 미분탄 저 NOx 버너 모델

탈질 기술 (DeNOx)

두산 밥콕과 협력하여 국내 최고 사양의 저 Nox 미분탄 버너 독립모델(D-NOx™ 버너)을 개발 완료하고 영흥 5,6 호기, 신보령 1,2호기에 적용함



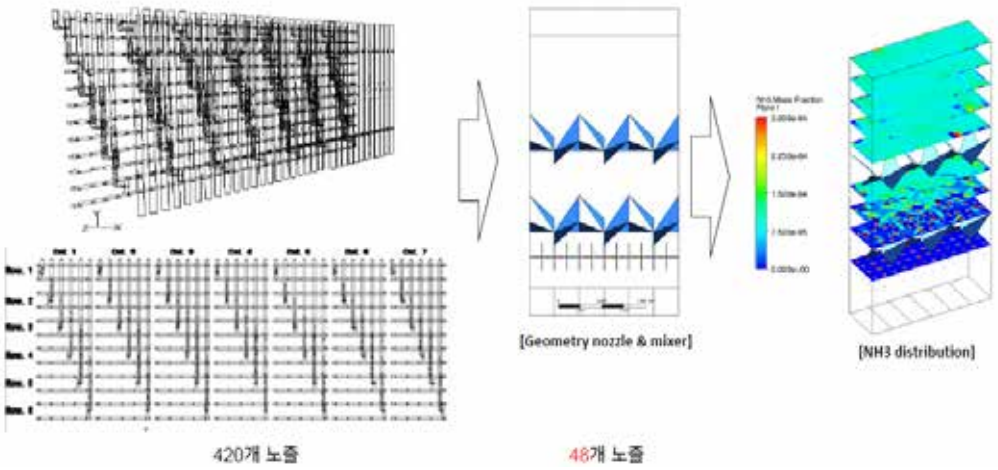
저 NOx 미분탄 버너 독립모델 (2007)

SCR- AAIG 개발

탈질 기술 (DeNOx)

NOx와 Ammonia의 균등 분배 및 혼합을 위한 AAIG (Advanced Ammonia Injection Grid) 기술 개발을 통해 Ammonia slip 최소화 및 95%이상 탈질 성능을 가지는 SCR 을 개발함

Old AIG(Ammonia Injection Grid) system



420개 노즐

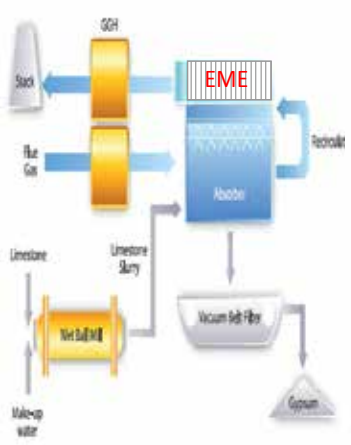
48개 노즐

두산 중공업 탈진(DeDust) 기술
EME-PM10/PM2.5, 전구 물질(SO3)

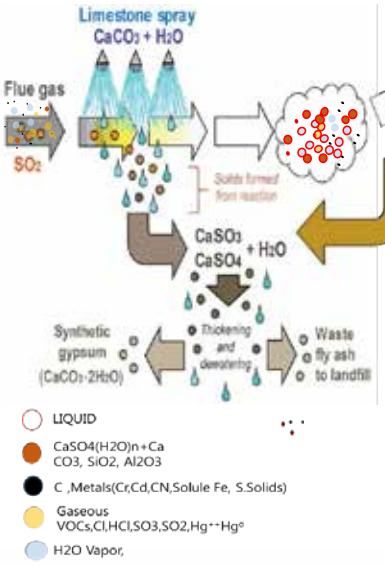
EME (Electrostatic Mist Eliminator) 소개

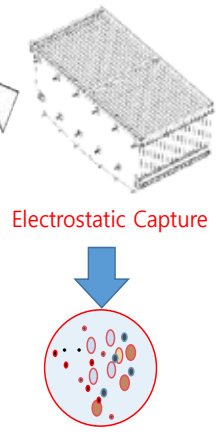
탈진 기술 (DeDust)

EME는 기존 ME에 Wet ESP 기술을 결합시킨 설비로서 ME가 제거 할 수 없는 20 μm 이하의 미세 먼지 및 응축수를 낮은 차압으로 제거 가능한 높이 10m 이내의 compact한 설비임



▪ 탈황 계통도 (EME 포함)





응축된 수증기와 함께 10 um 이하의 전구 물질을 제거함

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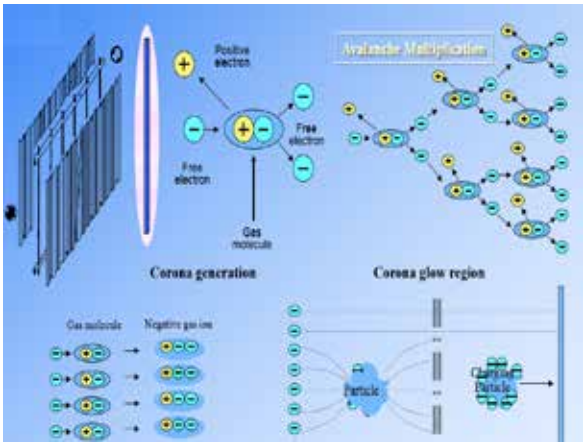
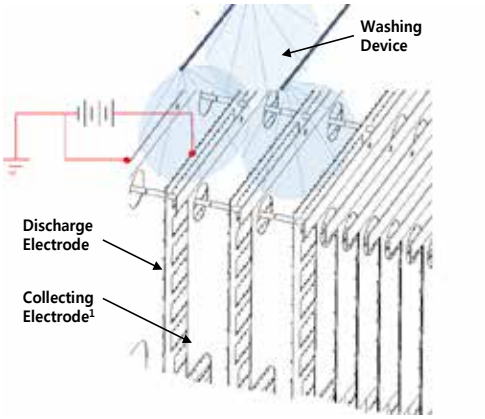
1) Mist: 엷은 안개, 박무, (에어로졸 같은) 스프레이 분무
2) 신서천: 30 mg/Sm³, 영흥#3,4: 50 mg/Sm³

EME(Electrostatic Mist Eliminator) 운전 원리

탈진 기술 (DeDust)

Wet ESP와 동일하게 코로나 방전 및 정전기력을 이용하여 응축수 및 미세 먼지을 포집하는 원리이며 Conventional Wet ESP 대비 집진판 길이 및 Pitch가 상대적으로 낮아 고 집진효율 및 경량화 구현





두산 Electrostatic Mist Eliminator

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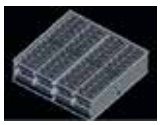
1. Collecting Electrode
   - Length : 두산 EME / 1.5m, Conventional WEST / 10m
   - Pitch : 두산 EME / 60mm, Conventional EME / 300mm

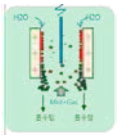
EME(Electrostatic Mist Eliminator)

탈진 기술 (DeDust)

미세먼지(PM10/PM2.5) 및 흡수탑 배출 MIST 저감 기술인 고효율 EME 개발을 국책과제를 통해 성공적으로 개발 완료함

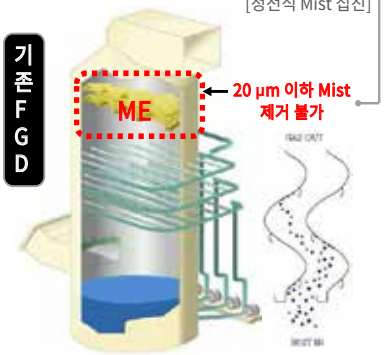
EME





[정전식 Mist 집진]

기존 FGD



[Absorber Mist Eliminator] [관성식 Mist 집진]

Electrostatic Mist Eliminator

[흡수탑 상부 설치 EME]

EME 개발 결과

- **연돌 백연 현상 50% 이상 저감**
  - 내부식성, 고하전 방전극 및 고효율 집진판 개발로 백연 (Mist+휘발성 유기화합물) 저감
  - 부분 Washing으로 Mist 배출 최소화
- **미세먼지 90% 이상 제거**
  - PM10/PM 2.5 90% 이상 제거
  - 집진판 간격 최소화하여 미세먼지 집진 성능 향상
  - 기존 Wet ESP 대비 스케일 형성 방지[1]
- **설치 기간 단축 및 유지보수 용이**
  - 고객 단납기(3개월) 요구 준수 가능
  - 소형 모듈화[2] 개발로 설비/유지보수 용이
  - 평판형 방전판/집진판 적용으로 세정불량 단점 극복

1. 집진판 길이 : 10M → 1.5M 감소로 세정 효과가 우수하여 하부 Scale 형성 방지
2. 소형 모듈화(Size) : 2.8L x 1.5W x 1.1H

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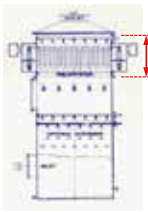
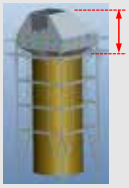
Wet ESP vs EME 비교

두산 중공업은 국내 최초로 compact, 고효율 EME를 개발하여 국산화에 성공 하였고 해외 선진사 대비 차별화된 기술임을 입증하였음

	Wet ESP (GE)	vs.	EME (Doosan)
구조 / 크기	 집진판/방전극 : Spike or wire형		 집진판/방전극 : 평판형
압력손실	• 40 ~ 45 mmH_2O		**• 20 ~ 22 mmH_2O (50%↓)**
소비동력	• 500 ~ 530 KW		**• 300 KW (40%↓)**
물량	• 150 ~ 180 ton		**• 80 ~ 100 ton (45%↓)**
설치면적	• 571 m^2		**• 200 m^2 (65%↓)**
설치기간	• 6개월		**• 3개월 (50%↓)**

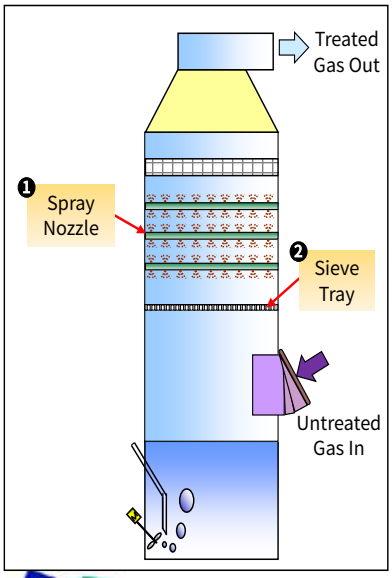
두산 중공업 탈황(DeSOx) 기술
FGD
NL GGH

황산화물 (1/2) – FGD 기술

탈황 기술 (DeSOx)

저압 Spray Nozzle 및 Sieve Tray(다공판) 개발을 통한 FGD 소비동력은 저감 시키고 탈황의 효율을 98% 이상 확보 할 수 있는 표준/신표준 화력 탈황 retrofit에 적합한 탈황 기술 개발

[Absorber Typical Section View]

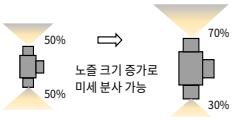


주요 기술 개발 내용

최종 Output

1 Spray Nozzle

- Pilot PJT를 이용한 저압 Nozzle 개발 및 성능 검증



- 저압 Spray Nozzle 개발
  - 입구압력 : 9.8 → 7.5psi
  - 소비동력 저감 : 216kW/unit

2 Sieve Tray

- 경쟁사 Tray Bench Marking
- Sieve Tray 설치에 따른 효율 개선 및 성능 검증

- **Sieve Tray 개발**

표준화력 FGD R&M PJT 대응 Solution 확보
- 단기간(3개월) 교체 가능

DOOSAN

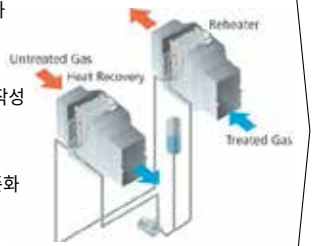
황 산화물 (2/2)- 탈황 기술 (Non-Leakage GGH 기술개발)

탈황 기술 (DeSOx)

국내 화력발전 배출기준[1] 강화에 따른 고효율 탈황설비용 NL GGH 기술 개발하였고 신서천 및 삼척 화력 FGD에 적용 함으로서 국내 최초로 국산화를 완료함

기술 개발 내용

- **핀-튜브 형상 및 튜브 배치기술 개발**
  - 튜브배열 및 형상 결정
  - 열교환기 전열성능 최적화
- **NL GGH 모델 설계**
  - 기본/상세 설계 및 도면 작성
- **설계 표준화**
  - 핀-튜브 설계 및 제작 표준화
  - 설계 계산서 표준화
- **설계 Tool Upgrade**
  - 전열면적 및 핀-튜브 배치 최적화



구 분	기술 개발 성과
A 기술 차별성	• **Cooler Tube 침식 방지 설계 적용** – Tube 사양 및 배열 최적화 설계 – CFD 해석 기반의 마모 보강재 위치 선정 • **Reheater 내부식용 코팅 적용(설비 안정성 향상)**

	코팅재질	시공방식	내구성
DHI	Phenolic	전면도장	4년
MHPS/IHI	Enamel	전면도장 (일부불가)[2]	2년

B 사업적 성과	• **설계 최적화를 통한 물량 절감 및 가격경쟁력 확보** – 영흥 3~5 NL GGH Cooler / Reheater Tube Bundle 교체공사 – 신서천 FGD NL GGH 제작 납품(국산화 초도품) – 삼척화력 FGD NL GGH 공급 예정 • **NL GGH 독자 설계 역량 확보** – Layout 최적화 및 압력손실 저감

1. 환경배출기준(충남조례기준) : SOx : 15ppm, 먼지 : 3~5mg/Sm³
2. U-Bend 부위 및 Fin Edge 전면도장 불가 (도장 실시 후 Enamel Coating 부위 Crack 발생됨)

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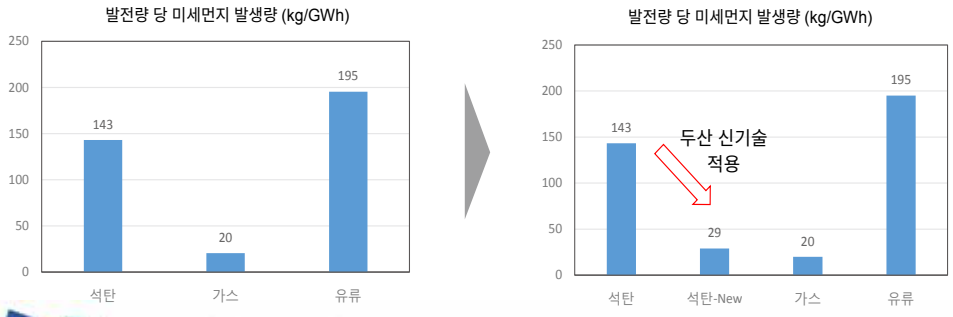
신기술 적용 시 석탄화력 발전 미세먼지 저감 효과

두산 중공업의 신 기술을 적용할 경우 발전양당 미세먼지 발생량은 LNG와 비슷한 수준으로 낮출 수 있음

개발 기술 적용 시

(미세먼지 기여도 SOx: 24.5%, NOx: 7%)

항목	현 수준	최고기술 적용	저감율	미세먼지 저감
Dust (mg/Nm3)	7	0.5	93%	95%
SOx (ppm)	30	5	93%	22.4%
NOx (ppm)	15	5	67%	4.7%



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중공업의 과학적 대처 방안

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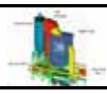
Appendix

두산 중공업 환경 설비

두산 중공업 환경 설비 list 및 공급 현황

Fuel		Present ~2019 OEM	Present ~2019 Under Developing	Future(2019~) Under Planning
SOx	Wet Limestone FGD	removal eff. upto > 99%, Reference 270 units	Optimized Doosan WLFGD – compact, low ΔP	Doosan Advanced WLFGD – low cost, compact design
SOx	Sea Water FGD	removal eff. > 96%, 6 units	Optimized Doosan SWFGD – compact aeration basin, low ΔP	Doosan Advanced SWFGD – Innovative process
SOx	Dry CFB FGD	removal eff. > 96%, 75 units 		Optimized dry CFB FGD – compact, low cost
NOx	SCR	removal eff. > 96% < 10 ppm 65 units.		Catalyst for Hg and N_2, advanced AIG system
PM	ESP	Dust contents Below 10mg/Nm³ / Dry ESP type Reference 1,323 units		EME (Electrostatic Mist Eliminator) for $PM_{2.5}$ SO3, and Hg
PM	Fabric Filter	High and low pressure pulse jet fabric filter 256 units		Hybrid FF (Dry ESP+ FF) for $PM_{2.5}$ and Hg
CO2	Post carbon capture	5 MWe plant		Commercialization from 2020
CO2	Oxyfuel	100 MWe Design concept (2012) and Demonstration plant (2020)		

Note

Note

Note

Note

SESSION 2

미세먼지 저감 기계기술

한국기계연구원 미세먼지 저감 연구개발 현황 및 발전방향

KIMM's Research Status on
Fine Particle Reduction and Development Plans

>> 한국기계연구원 한방우 환경기계연구실장

Bang Woo Han / Dept. Head, KIMM / Korea

[발표자료 비공개]

『2019 글로벌 기계기술 포럼』 사무국
34103 대전광역시 유성구 가정북로 156 한국기계연구원 대외협력실
Tel : +82 42-868-7329 E-mail : san@kimm.re.kr

2019 GLOBAL FORUM ON MECHANICAL ENGINEERING

2019 글로벌 기계기술 포럼 https://forum.kimm.re.kr

미세먼지 해결을 위한 기계기술

KIMM 한국기계연구원
KOREA INSTITUTE OF MACHINERY & MATERIALS