华能清洁能源研究院
HUANENG CLEAN ENERGY RESEARCH INSTITUTE

燃煤电厂氧化协同脱汞技术应用研究

Study and Application of Mercury Control Technology in Coal-fired Power Plant

钟犁（ZHONG Li） 郭涛（GUO Tao）

中国华能集团清洁能源技术研究院有限公司

China Huaneng Clean Energy Research Institute

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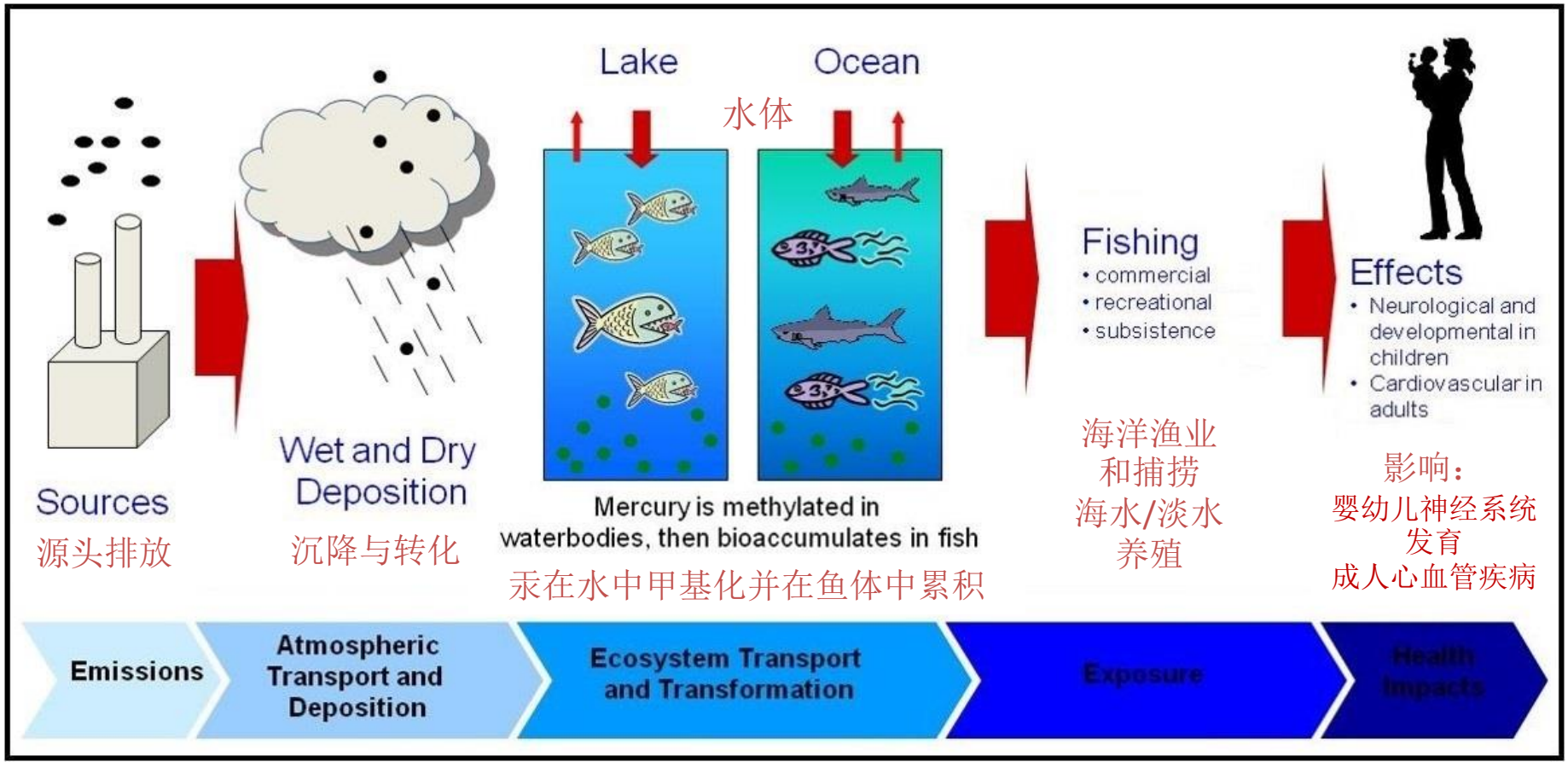
汞污染特性
Mercury pollution characteristics

汞是一种剧毒性物质，具有远距离传输、持久性、生物累积、遗传毒性等特点，会对环境、人体产生严重危害。Mercury is a toxic substance with the characteristics of long-range transport, persistence, bioaccumulation, genetic toxicity, can cause serious harm to the environment and human.



中国的燃煤电厂汞污染排放
Mercury emission of coal-fired power plant in China

- 在2011年7月29日最新公布的《火电厂大气污染物排放标准》（GB13223-2011）中，中国规定燃煤电站汞污染排放标准为**30 μg/m^3**

  According to “Emission standard of air pollution for thermal power plants” (GB13223-2011), the mercury emission standard for coal-fired power plants in China is 30 μg/m^3, implemented since January 1st, 2015

- 自2011年1月，中国正式启动了包括五大电力集团及神华集团在内的16家燃煤电厂的大气汞污染排放监测试点工作

  Since January 2011, China formally launched the atmospheric mercury emissions monitoring pilot project, in 16 coal-fired power plants

- 华能清能院负责其中3家燃煤电厂的汞污染排放监测

  CERI participated in this project, and is in charge of emission monitoring in 3 power plants

华能清能院汞排放监测设备
Mercury emission monitoring equipment in CERI

- 汞排放在线连续监测系统2套，符合美国EPA 30A方法要求，并采用车载方式
  Hg-CEMS, in accordance with EPA Method 30A, is designed to be used in car
- 吸附管法汞采样设备2套，汞分析仪1套，汞吸附管若干，符合美国EPA Method 30B、7473等要求 Sorbent traps mercury sampling equipment, mercury analyzer, in accordance with EPA Method 30B, 7473 and other requirements
- OHM汞排放监测设备1套
  OHM mercury monitoring equipment

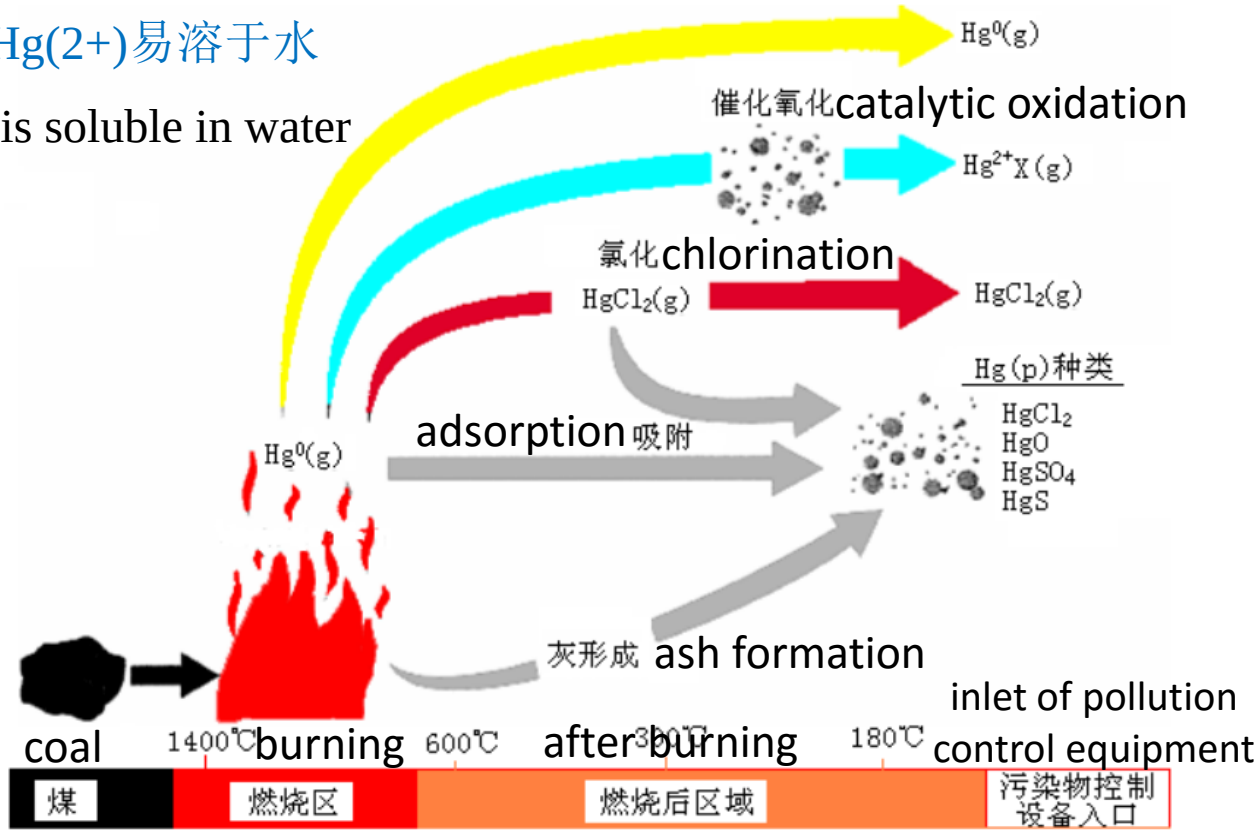
汞在燃煤过程中的形态转换
Mercury speciation transformation in coal-fired process

- 燃煤电厂最终排放的汞，分为气态元素汞、气态二价汞、固态颗粒汞

  Mercury emissions in coal-fired power plants include: gaseous elemental Hg(0), gaseous oxidized mercury Hg(2+), and particle-bound mercury Hg(P)

- 其中，Hg(2+)易溶于水

  Hg(2+) is soluble in water



汞的形态对协同脱汞的影响
The effect of mercury speciation on co-benefit removal

- 如上所述，汞的形态对协同脱汞的效果影响巨大，其中，固态颗粒汞最容易被协同脱除，气态二价汞其次，气态单质汞最难被协同脱除

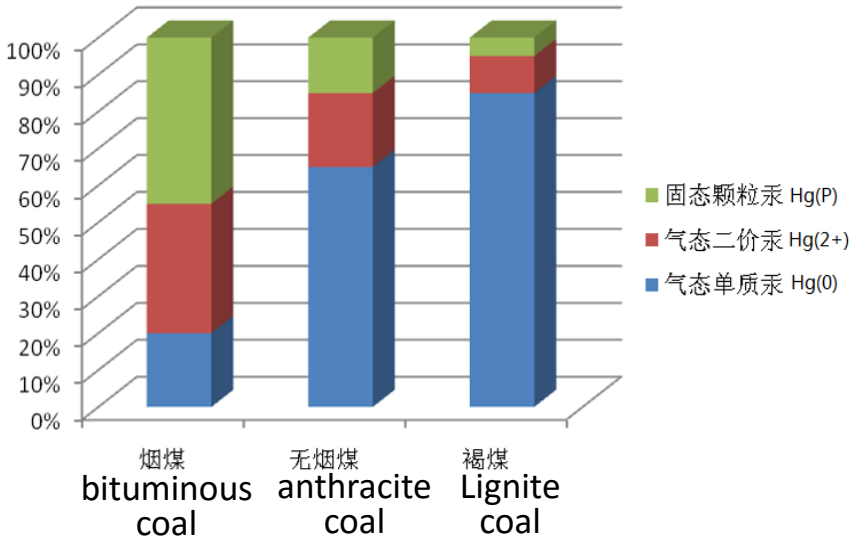
  The effects of mercury speciation on co-benefit removal is huge. Hg(P) is most easily to be removed, Hg(2+) comes second, while Hg(0) is the most difficult to be removed

- 煤质是影响汞形态分布的最重要因素，因此可通过适当的配煤，降低汞排放

  Coal is the main factor influencing mercury speciation, therefore, when conditions allowed, appropriate blending can help reducing mercury emissions

- 飞灰含碳量高，颗粒汞的比例越高，但不可能通过这种方法来提高脱汞效果

  Generally, the higher percentage of carbon in fly ash, the higher that of Hg(P), but this method can’t be used to improve the Hg removal



燃煤电厂协同脱汞技术
Co-benefit mercury control technique

- 依靠现有烟气净化设备实现汞污染控制，成本较低，且中国烟气净化系统普及率高，适合优先考虑。The pollution control equipments existing in power plant have co-benefit control effect on mercury, if we can maximize the co-benefit effect, the cost would be low.
  - 除尘器 dust collector such as ESP (electro-static precipitator) and FF(fabric filter)：
    - ✓ 有效脱除固态颗粒汞，适用于所有电厂

      Can remove most Hg(P), and is suitable for almost every power plant
    - ✓ 布袋除尘器上的飞灰可以对气态汞进一步吸附，因此脱除效果更佳

      FF has better effect, because the ash in FF can adsorb some gaseous mercury
  - SCR烟气脱硝系统 Selective Catalyst Reduction of flue gas denitration system：
    - ✓ 可以在一定程度上促进单质汞的氧化

      Can promote the oxidization of mercury, then the Hg(2+) can be easily removed by WFGD or other equipment

燃煤电厂协同脱汞技术
Co-benefit mercury control technique

- WFGD湿法烟气脱硫 Wet flue gas desulfurization：
  - ✓ 可以脱除气态二价汞，对单质汞无脱除效果

    Can remove most Hg(2+) by water, while no effect on Hg(0)
  - ✓ 实测中国采用WFGD的若干机组，自脱汞率在35%~65%

    We measured some units applied WFGD and ESP in China, the national mercury removal rate is about 35%~65%
- 干法、半干法烟气脱硫 Dry or semi-dry flue gas desulfurization ：
  - ✓ 对单质汞和气态二价汞均有一定的脱除效果

    Can remove both Hg(0) and Hg(2+) by adsorbent
  - ✓ 实测中国某采用半干法脱硫的机组，自脱汞率约为80% We measured a units applied CFB-FGD in China, the national mercury removal rate is about 80%

■ 另外，机组效率越高，同样发电量下的汞排放量也就越低 Besides, the higher unit efficiency, the lower mercury emission for the same power generating

促进协同脱汞技术-氧化
Promote co-benefit effect - mercury oxidation

可以采用以下措施，促进汞的氧化，以提高协同脱汞效果。 There are some methods we can use to promote mercury oxidation, in order to increase co-benefit effect.

- 煤添加剂 Coal additive：
  - ✓ 促使烟气中气态单质汞的氧化，提高二价汞和颗粒汞的比例

    Promote the oxidation of Hg(0) in flue gas to convert to Hg(2+) and Hg(P) effectively
- 基于WFGD的添加剂 The additives based on WFGD：
  - ✓ 通过加入稳定剂，防止氧化汞还原，保证脱汞效率

    Adding stabilizer to prevent the reduction of Hg(2+), ensure removal efficiency
  - ✓ 通过加入氧化剂，促进WFGD中单质汞的氧化，提高脱汞效率

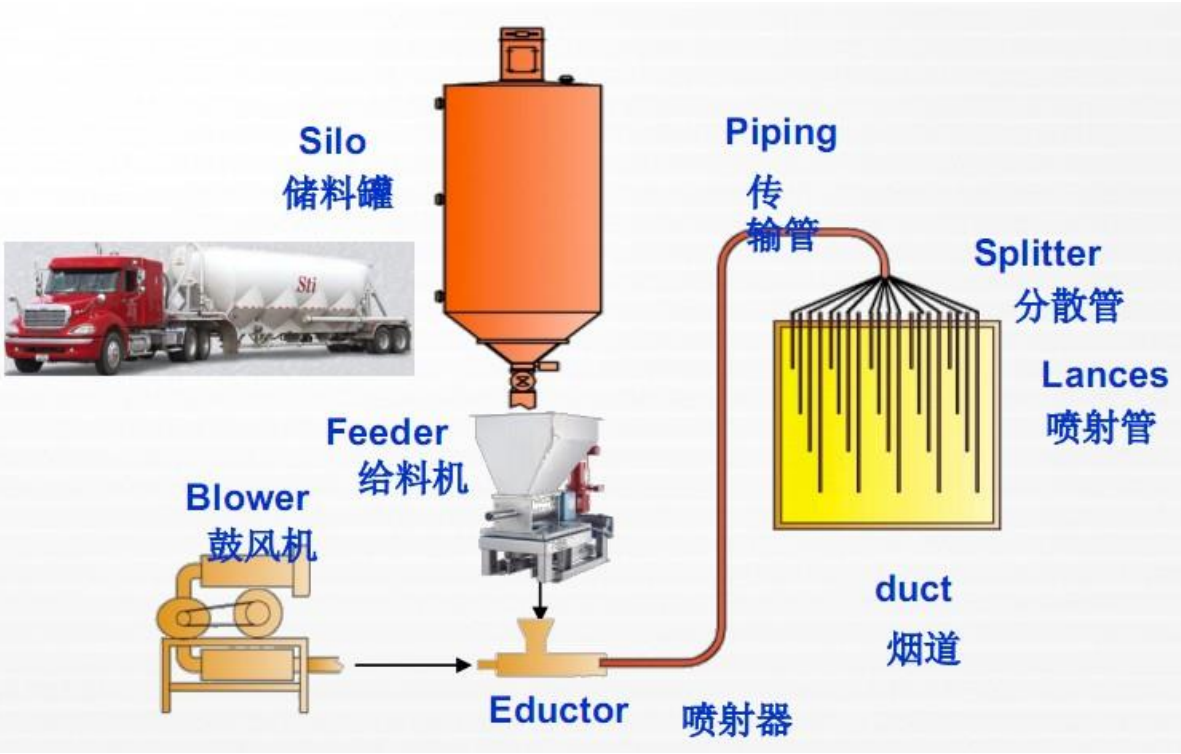
    Adding oxidizing agent to oxidize Hg(0) in WFGD, improve removal efficiency
- 基于SCR的催化剂优化 Catalyst optimization based on SCR：
  - ✓ 提高SCR催化剂对单质汞的氧化效果

    Improve the oxidation effect of SCR catalyst on the elemental mercury

燃煤电厂吸附脱汞技术
Mercury adsorption technology

- 吸附脱汞原理 Principle of adsorption
  - 采用活性炭、改性活性炭等吸附剂，实现对气态汞的吸附 Adsorb the gaseous mercury using adsorbent such as activated carbon, modified activated carbon
  - 物理吸附、化学吸附 Including physical adsorption and chemical adsorption
- 技术的优点 The advantages
  - 适应性广，脱除效率高 Wide adaptability, high removal efficiency
  - 不会引起二次污染：在常温条件下，飞灰中的汞不浸出 Don't cause secondary pollution: the captured mercury is stable, the leachate mercury is quite minimal
- 技术的缺点 The disadvantages
  - 运行成本高昂：普通活性炭使用量大，改性活性炭单价高
  - The cost is high: would use lots of ordinary activated carbon, using modified activated carbon can decrease the total amount while the unit-price is high

燃煤电厂吸附脱汞技术
Mercury adsorption technology



吸附脱汞示意图

Sketch map of Activated Carbon Injection (ACI)

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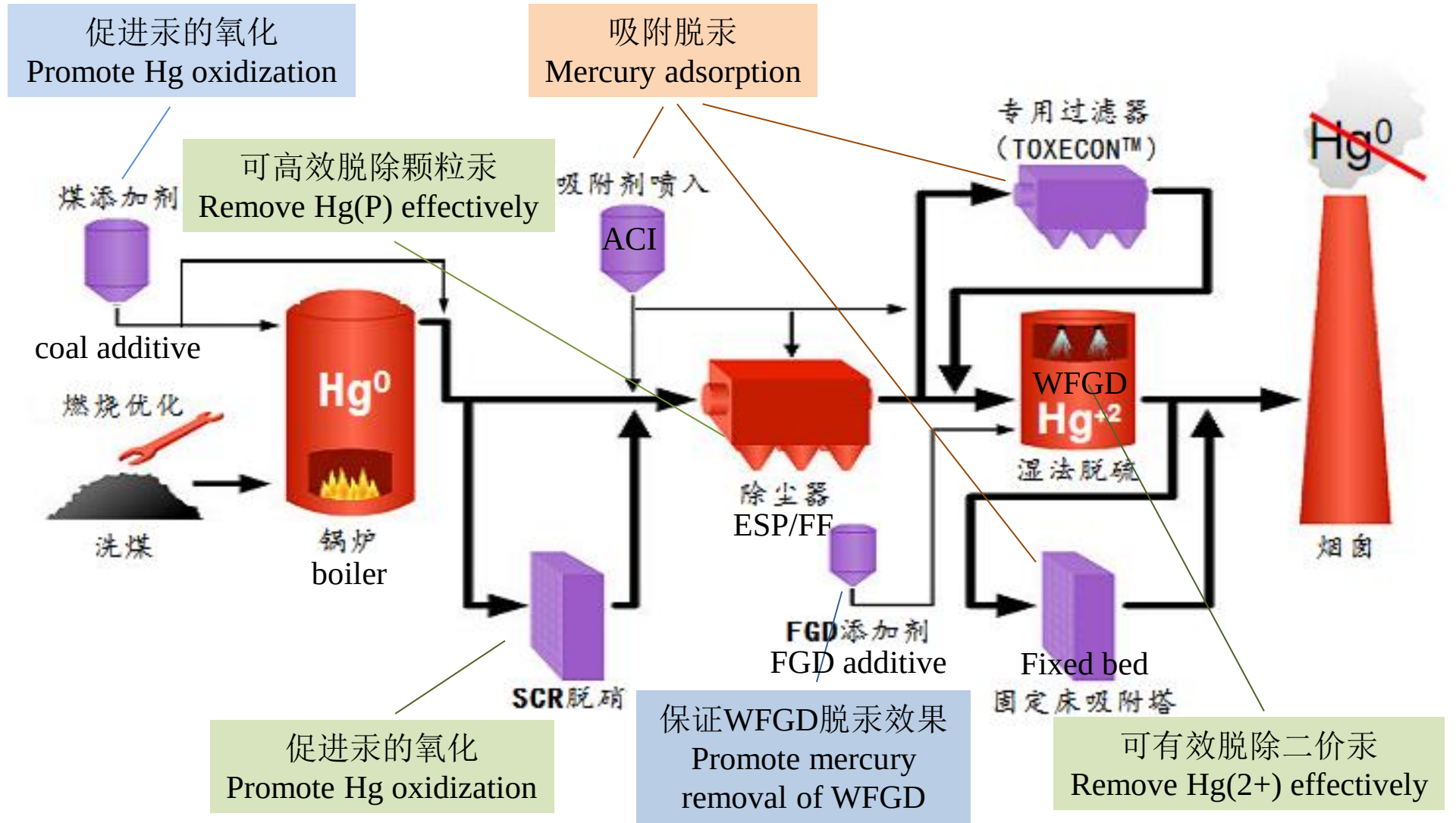
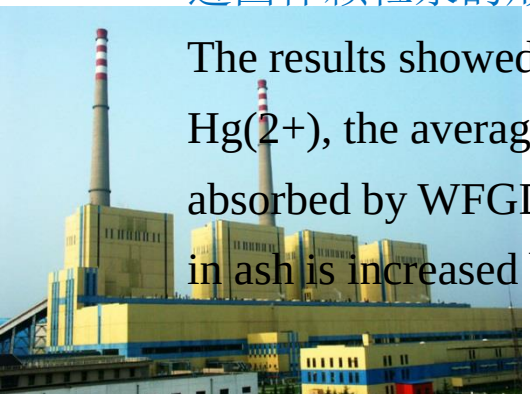
燃煤电厂汞污染控制技术
Mercury control technology for coal-fired power plant



北京某电厂汞污染控制应用
Mercury control for a power plant in Beijing

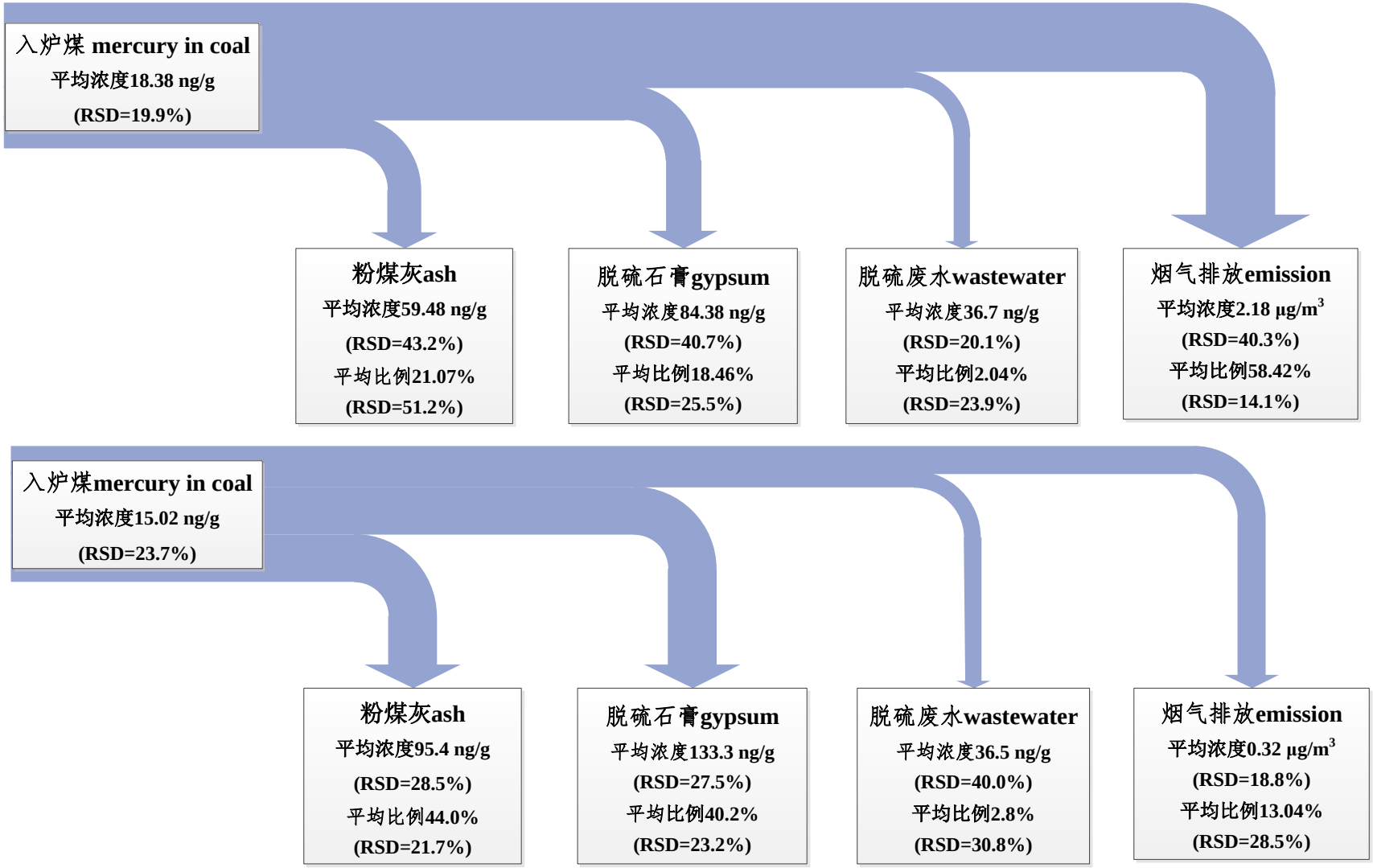
- 北京某电厂具有SCR+ESP+WFGD的典型烟气净化系统，基于协同脱汞技术，开展了汞污染控制应用研究，通过加入煤添加剂和稳定剂，有效促进协同脱汞效果，在中国首次成功实现了全烟气流量的汞污染控制。 For a power plant in Beijing with typical system of SCR+ESP+WFGD, we studied the mercury emission characteristic, then researched on the most suitable mercury control scheme. Finally, by adding coal additive and stabilizer to promote the co-benefit mercury removal effect, we achieved total flue gas flow mercury control for the first time in China.
- 试验结果表明：煤添加剂加入后，有效促进了烟气中的气态元素汞氧化为气态二价汞，脱硫前二价汞的比例平均由26%增至88%，然后被脱硫塔吸收；并且可以促进固体颗粒汞的形成，使灰中平均汞浓度提高了60%，从而提高整体的脱汞效率。The results showed that: coal additives effectively promoted the oxidation of Hg(0) to Hg(2+), the average ratio of Hg(2+) before WFGD increased from 26% to 88%, and then absorbed by WFGD; also promoted the formation of Hg(P), the mercury concentrations in ash is increased by 60%, thereby improved the whole mercury removal efficiency.



北京某电厂汞污染控制应用
Mercury control for a power plant in Beijing

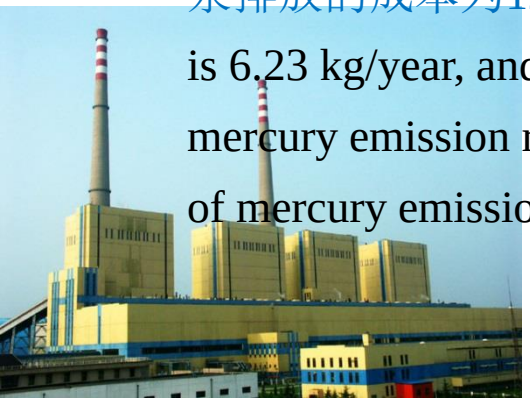
- 脱汞前：脱硫前二价汞的比例平均为**26.2%**，脱硫后平均大气汞排放浓度为**2.13** μg/m^3，灰中平均汞浓度为**59.5** ng/g，机组的平均自脱汞率为**41.9%**，大部分汞随烟气排放。Before mercury control: the average ratio of Hg(2+) before WFGD was 26.2%, the average atmospheric mercury emission concentration was 2.13 μg/m^3, the average mercury concentration of ash was 59.5 ng/g (ppb), the natural mercury removal rate was 41.9%, most mercury was emitted with stack gas.
- 脱汞后：脱硫前二价汞的比例平均达到**88.1%**，脱硫后大气汞排放均值为**0.32** μg/m^3，灰中平均汞浓度为**95.4** ng/g，而脱汞效率均值为**87.0%**，大部分汞进入飞灰和石膏。 After mercury control: the average ratio of Hg(2+) before WFGD is 88.1%, the average atmospheric mercury emission concentration is 0.32 μg/m^3, the average mercury concentration of ash was 95.4 ng/g, the average mercury removal rate is 87.0%, most mercury is captured in ash and gypsum.

北京某电厂汞污染控制应用
Mercury control for a power plant in Beijing



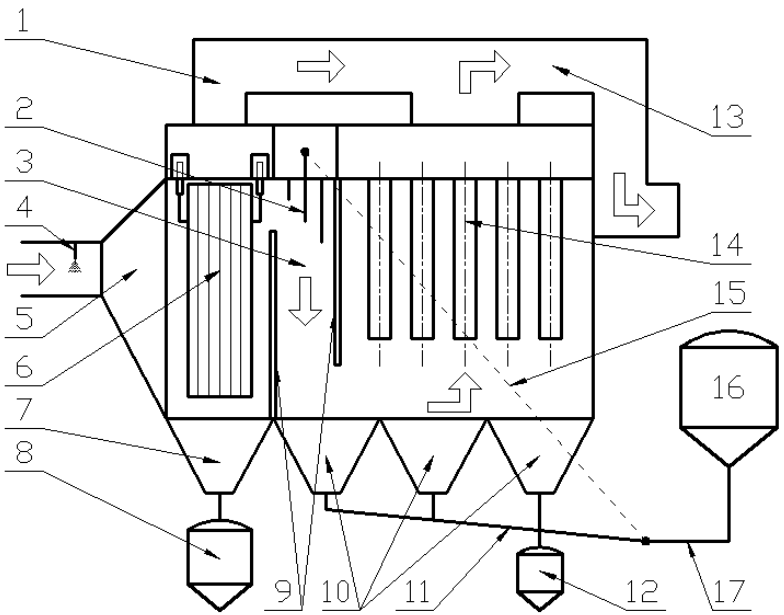
北京某电厂汞污染控制应用
Mercury control for a power plant in Beijing

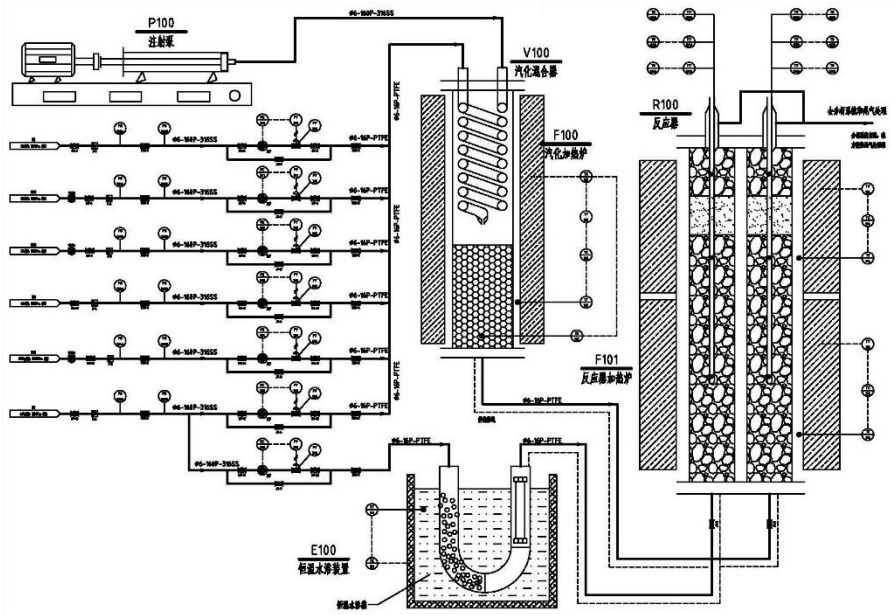
- 试验结果表明：大气汞排放均值由2.13 μg/m^{3}降至0.32 μg/m^3，机组脱汞效率均值由41.9%提高到87.0%。The results showed that: the mean atmospheric mercury emissions decreased from 2.13 μg/m^3 to 0.32 μg/m^3, and the average unit mercury removal efficiency increased from 41.9%(national) to 87%.
- 经济性：汞污染控制系统的年运行成本约为60万，折合0.05 分/kWh，成本较低。Economically: the annual operation cost for mercury control is about 600,000 yuan, equivalent to 0.05 yuan/kWh, so the cost is low.
- 环保效益：单台机组的原始汞排放量为6.23 kg/年，实施汞污染控制后的汞排放量约为1.39 kg/年，每年可减少4.84 kg的汞排放，减排77.6% ，折合每减少1 kg大气汞排放的成本为12.4万元。Environmentally: the original mercury emission of one unit is 6.23 kg/year, and decreased to about 1.39 kg/year after mercury control. So the mercury emission reduces 77.6%, or 4.84 kg per year. Which means, to reduce every kg of mercury emission, the cost is 124,000 yuan.



吸附脱汞技术研究
Research on mercury adsorption technology

- 通过理论研究和数值模拟，对吸附脱汞工艺进行优化 Through theoretical research and numerical simulation to optimize mercury control process.
- 廉价高效吸附剂的研发：建立吸附脱汞试验台，开展褐煤提质制活性炭等吸附剂的研究工作。 Research on cheap and efficient adsorbent: we established a adsorption test bench, to develop adsorbent such as activated carbon produced by lignite upgrading.





谢谢！

Thank you!