柴油车排放遥感监测的挑战
Challenges for Remote Sensing Detection of Diesel Emissions

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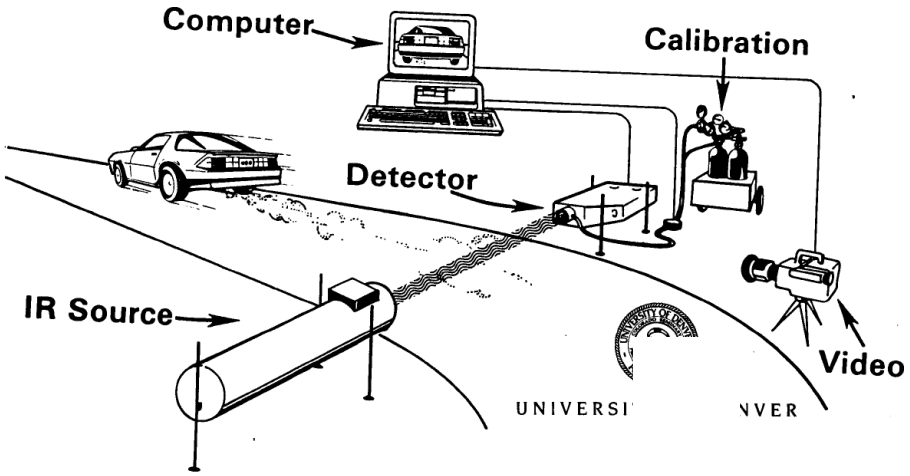
机动车环保监测要求
Regulatory requirements

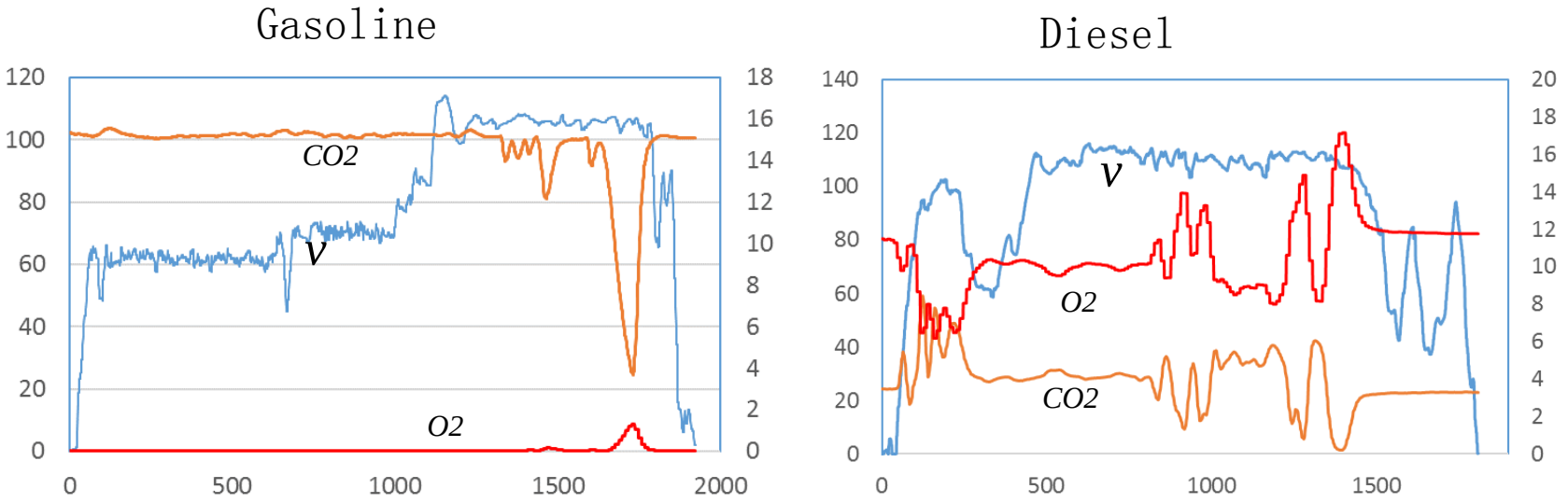
- 基于环境管理需要,需要重点加强对柴油车的排放监督管理，柴油车的主要污染物是颗粒物排放和NOx排放；
- **Strengthen the in-use monitoring of diesel NOx and PM;**
- 遥感监测理论起源于对汽油车（当量空燃比的燃烧），汽油车理论相对比较完善，而柴油车理论不够完善；
- **RSD algorithm oriented from stoichiometric engines, issues exist for diesel application;**
- 柴油车颗粒物表现形式：颗粒物质量排放、数量排放、烟度排放；
- **Diesel PM metrics: particle mass, particle number and smoke opacity;**
- 颗粒物排放到大气中自然沉降，可能不满足扩散物之间浓度关系比例不变假设，反演计算更加困难。
- **Unlike gaseous emissions, particle transport and condensation in the atmosphere may disobey the classical assumption, making the inversion calculation of raw emission concentrations even harder.**

排放遥感监测的理论基础
RSD fundamentals



- 假设排气烟羽经大气扩散后,各种污染物之间的比例不变;
- **Pollutant concentrations relative to CO_2 keep unchanged after entering the atmosphere;**
- 根据内燃机燃烧理论,反演排气管中各污染物的浓度;
- **Inversion calculation of raw emission concentrations based on combustion equations;**
- 污染物比例不变假设对柴油车烟度不一定适用。
- **“Unchanged concentration Ratio” assumption arguably works with diesels**

汽油车和柴油车的不同排气特征
Gasoline and Diesel Exhaust



汽油车排气中CO2几乎保持不变，O2浓度接近0；

CO2 in the gasoline exhaust keep constant,O2 near zero

柴油车排气中CO2浓度在很大范围内变化，并且有大量的剩余氧气；

CO2 and O2 in the diesel varies in wide range

排气中CO2和O2特征的差异，导致需要采用不同的数学计算模型，以反演计算排气管中污染物的浓度

The difference of the CO2 and O2 in the exhaust ,need different calculation model

内燃机基本燃烧方程
Combustion Equation of IC Engine

- 遥感方程，基于内燃机基本燃烧方程，该方程的基本特征是燃烧产物中没有剩余的氧，适合当量比燃烧的点燃式发动机，不适合富氧燃烧的柴油机，柴油机的过量空气系数可以在1.3-10之间变动：
- **RSD equation was derived from the combustion equation of SI engines where no residual O_2 exists in the exhaust, diesels are air-rich so disobeying this rule, lambda for diesels can range from 1.3 to 10:**

$$CH_2 + m(0.21O_2 + 0.79N_2) \rightarrow aCO + bH_2O + cC_4H_6 + dCO_2 + eNO + (0.79m - \frac{e}{2})N_2$$

- 基于上述方程，推到得到：
- **Based on the above equation, we can have:**

$$\%CO_2 = \frac{42}{2.79 + 2Q + 1.21Q' + Q''}$$

$$Q = CO/CO_2$$

$$Q' = HC/CO_2$$

$$Q'' = NO/CO_2$$

其它方程
Other equations

- 完全燃烧方程，汽油车[CO_2]在15.0%左右
- **For complete combustion, CO_2 remains at 15.0% in gasoline exhaust**

$$[NO] = \frac{NO\ (ppm - meter)}{CO_2\ (ppm - meter)} * [CO_2]_s$$

- 不完全燃烧方程，汽油车[CO_2]在14.0-15.0%左右
- **For incomplete combustion, CO_2 varies from 14.0 to 15.0%**

$$[NO] = \frac{NO\ (ppm - m)}{CO_2\ (ppm - m) + CO(ppm - m) + 3 * HC(ppm - m)} * [CO_2]_s$$

- 柴油车基本按完全燃烧考虑， [CO_2]在2.0-10.0%之间较大幅度变化,剩余氧多,上述公式不再适用
- **Diesel combustion is considered complete, CO_2 varies from 2.0 to 10.0%, A lot of oxygen left**

Source: José Luis Jiménez-Palacios, Understanding and Quantifying Motor Vehicle Emissions with Vehicle Specific Power and TILDAS Remote Sensing

其它方程
Other equations

- 汽油车[CO_2]也可基于燃料的不完全燃烧方程
- **Gasoline CO_2 concentrations can be also calculated via incomplete combustion equation**

$$\%\ CO_2 = 42/(2.79 + 2Q + 0.42Q')$$

$$\%\ CO = Q(\%\ CO_2)$$

$$\%\ HC = Q'(\%\ CO_2)$$

$$\%NO = Q''(\%\ CO_2)$$

上述公式同样只是适合汽油车，不适合柴油车。
The above equation is only valid for gasoline

Source :G. A. BISHOP, Acc. Chem. Res. 1996, 29, 489-495

柴油车可能的解决方案
Possible Solutions for Diesel

- 目前的成熟理论，能够根据排气烟羽中各种污染物的浓度之间的比例关系，反演推算得到汽油车排气管中的污染物浓度，但上述公式不适合柴油车。
- **Based on the pollutant concentration in the plume ,we can work out the gasoline tailpipe concentrations,but the theory is not valid for diesel**
- 基于车辆运行参数回归得到排气管中CO_2的浓度，根据各种污染物的浓度比，反演得到排气管中主要污染物浓度(主要指NO)。
- **Predict tailpipe CO_2 concentrations based on vehicle dynamic parameters, and work out pollutant concentrations based on measured pollutant/CO_2 ratios (mainly NO).**
- 或者，基于燃油或者CO_2的排放因子；
- **Or, fuel-based or CO_2-based emission factors;**
- 根据排气烟羽中NO/CO_2的浓度比，获得基于NO/kg Fuel的排放因子。
- **Work out NO/kg fuel emission factors based on NO/CO_2 ratios in exhaust plumes.**

比功率问题
Vehicle specific power (VSP)

- 机动车比功率：机动车单位质量瞬时功率的概念，是发动机克服车轮旋转阻力（$F_{rolling}$）、空气动力学阻力（$F_{Aerodynamic}$）做功以及增加机动车的动能（E_k）和势能（E_p）所需要输出的功率和因内摩擦阻力（$F_{internalfriction}$）造成的传动系的机械损失功率。其数值与速度和加速度有关，数学表达式为：
- **VSP is the power consumed at the moment (including wheel rolling, aerodynamic drag, internal friction and increase in mechanical energy) divided by vehicle mass. Mathematically, VSP is a function of vehicle speed and acceleration.**

$$VSP = \frac{\frac{d}{dt}(E_K + E_P) + F_{rolling} \bullet v + F_{Aerodynimic} \bullet v + F_{internalfriction} \bullet v}{m}$$

$$= \frac{\frac{d}{dt}(\frac{1}{2} m \bullet (1+\varepsilon_i) \bullet v^2 + m \bullet g \bullet h)) + C_R m \bullet g \bullet v + \frac{1}{2}\rho_a C_D A (v + v_W)^2 \bullet v + C_{if} m \bullet g \bullet v}{m}$$

$$= V \bullet (a \bullet (1+\varepsilon_i) + g \bullet s + g \bullet C_R) + \frac{1}{2}\rho_a \frac{C_D A}{m}(v + v_W)^2 \bullet v + C_{if} \bullet g \bullet v$$

比功率问题
Vehicle specific power (VSP)

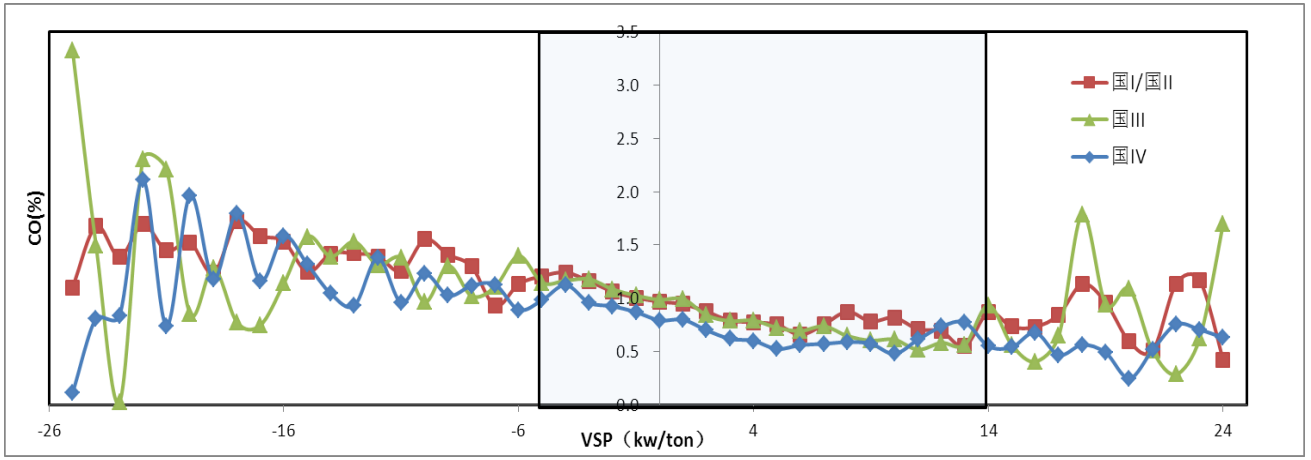
- 对乘用车，近似简化处理得到VSP简化公式：
- **For passenger cars, VSP can be calculated by using the following method:**

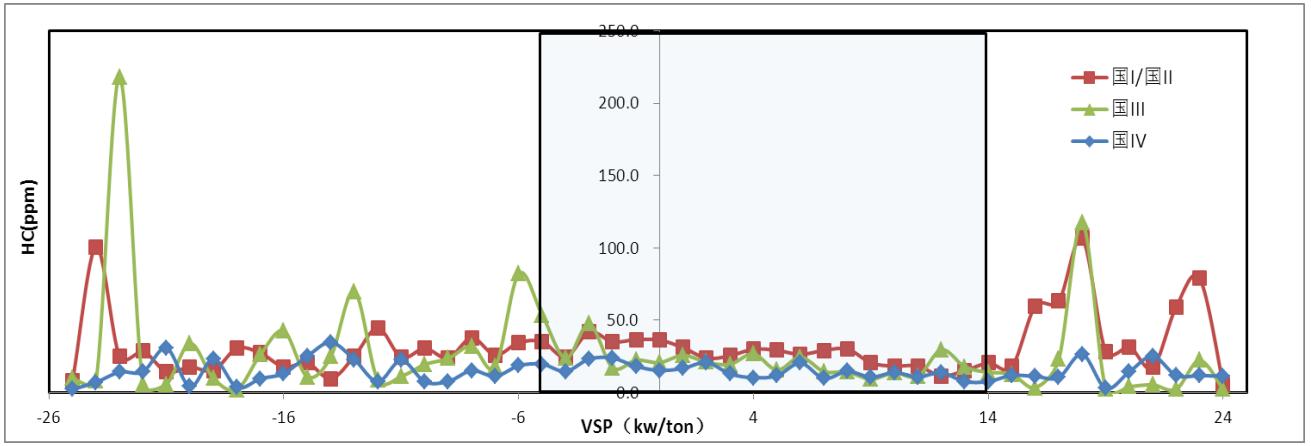
$$VSP = 2.7284 \bullet \sin(slope) \bullet v + 0.305924 \bullet v \bullet a + 0.05921 \bullet v + 6.52981 \times 10^{-6} \bullet v^3$$

- 对商用车，无法进行简单简化处理，乘用车简化公式不再适用；
- **The above method doesn't work with HD vehicles**;
- 对乘用汽油车 VSP主要用于判断汽车排放稳定区间；
- **The aim to set VSP threshold is to check if the car is within an emission-stable margin;**

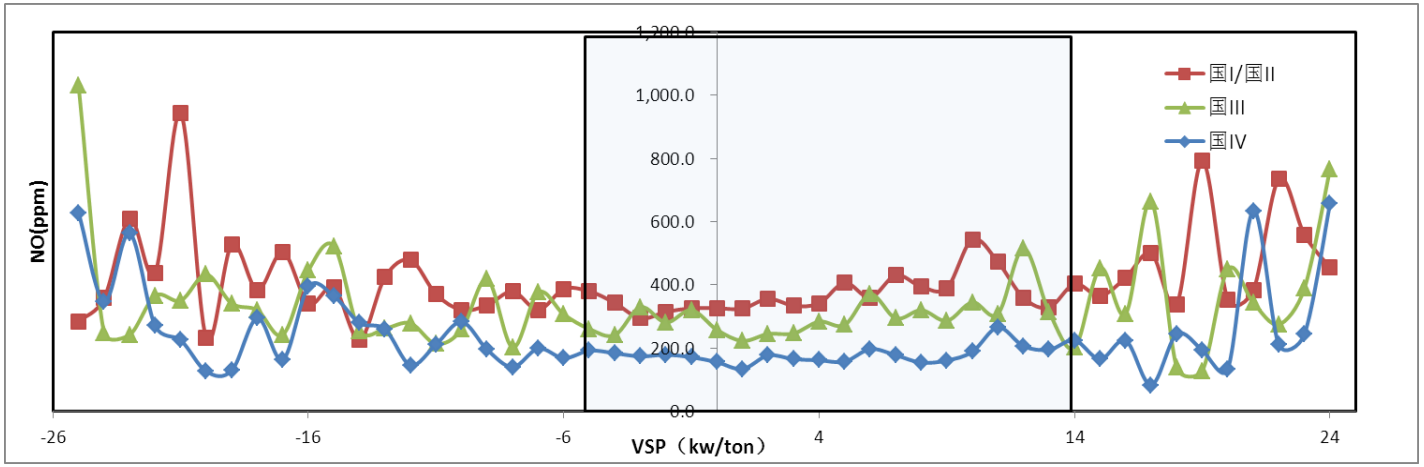
  柴油车排放特性不同于汽油车排放特性，VSP不能简单引用；
- **Diesel emission characteristics are different from gasoline, diesels shall have their own VSP requirements;**
- 如果用于豁免排放，可以基于车辆加速度进行判断，加速度为负值状态不适合豁免条件。
- **Acceleration ratio can be a good metric for clean vehicle screening, negative accelerations are not suitable for clean screening judgement**

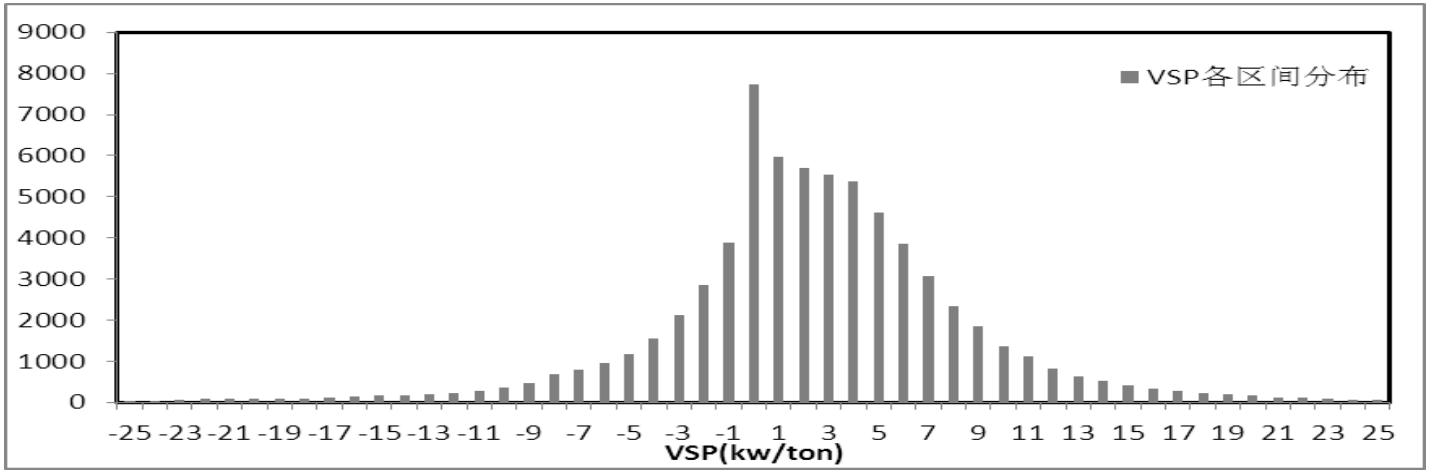
VSP 和排放
VSP and Emission





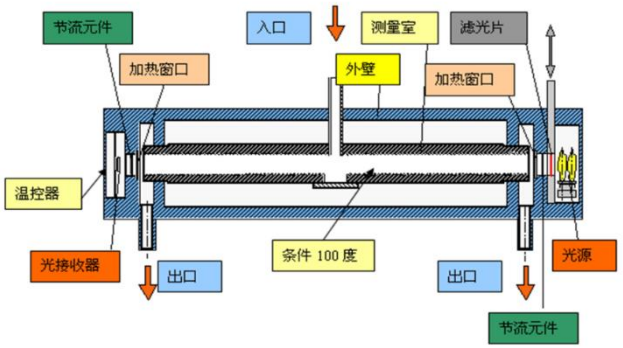
VSP 和排放
VSP and Emission



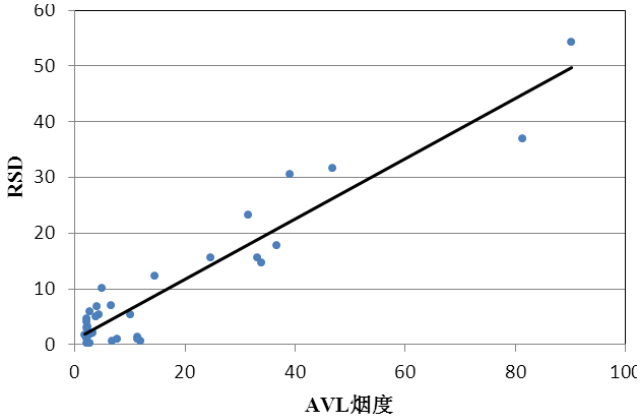


柴油车烟度遥感测量
RSD for diesel smoke

- 与不透光度烟度计测量原理相同；
- **Measurement algorithm is the same with smoke opacity meter**;
- 直接测量得到的的是烟雨羽扩散后的不透光烟度，不是排气管烟度；
- Measurement is made based on diluted exhaust in the atmosphere;
- 不同设备供应商的光程长度不同，对测量结果影响需要修正？
- **Wave length varies from make to make, result correction needed?**
- 不同位置排气管烟羽的捕捉率问题
- **Some configurations of tailpipe may obscure measurement**

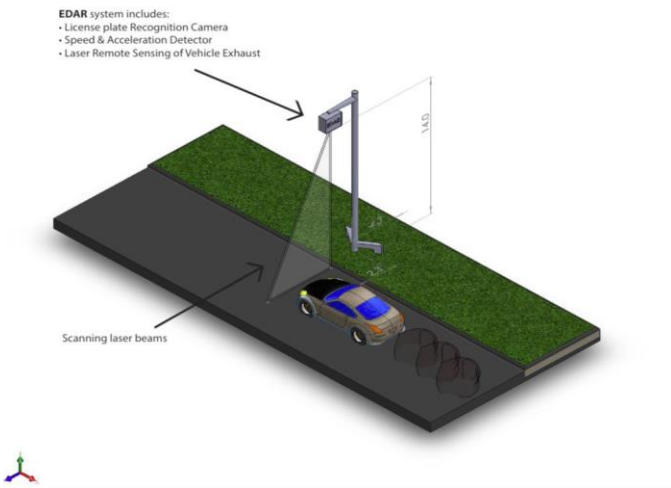


遥感与不透光烟度的相关性
Correlation between RSD and smoke opacity



- 静态烟度测量，没有考虑车辆行驶速度的影响；
- **Steady-state smoke measurement, the impacts of driving are excluded;**
- 扩散后的稀释后的烟度，不是排气管的烟度
- **Opacity was measured after air dilution instead of at the tailpipe exit**
- 如何反演回排气管的烟度？
- **How to back-calculate the smoke opacity at the tailpipe exit?**

基于结构设计提高捕捉率
Promoting work efficiency by appropriate arrangement



进一步的研究课题
Questions to be answered

- 汽油车统一反演计算公式？
- **Uniformed gasoline RSD calculation algorithm?**
- 柴油车NOx排放浓度反演到排气管的问题
- **How to accurately predict tailpipe diesel NOx concentrations?**
- 柴油车NOx排放评估方法
- **Method for diesel NOx evaluation**
- 基于排气管浓度ppm？
- **Tailpipe concentration based?**
- 基于 NO/CO2？
- **NO/CO_2 based?**
- 基于 NO/(kg Fuel)？
- **NO/(kg Fuel based？**
- 烟度排放，需要有合适的评价方法
- **Smoke opacity needs appropriate method to be evluated**

谢谢聆听！

Thanks for Your Attention！

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