Supplemental Material for

Investigation of aerosol and gas emissions from a coal-fired power plant under various operating conditions

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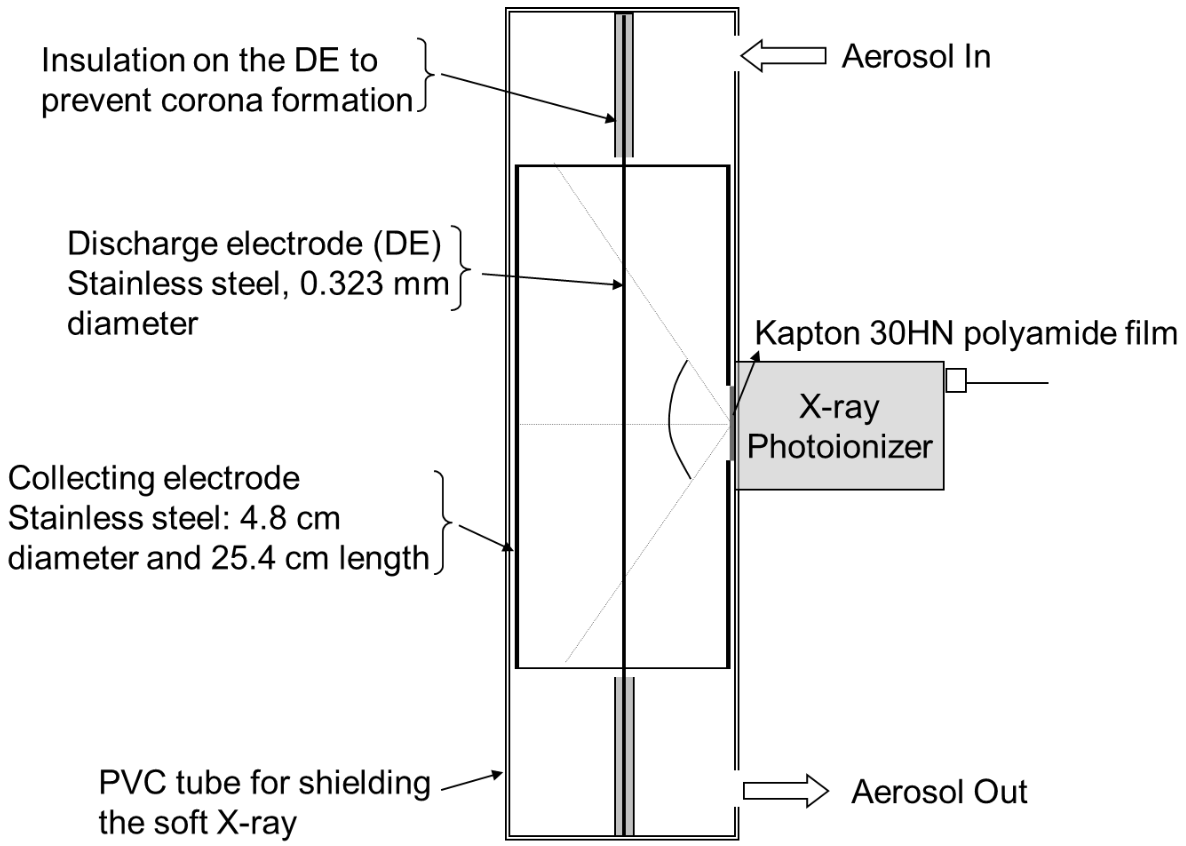


Figure S1. Configuration of the soft X-ray (SXR)-enhanced ESP used in the experiment. (The soft X-rays emitted by the photoionizer entered the ESP body through a circular hole (1.7 cm in diameter). A thin polyamide film (Kapton® 30HN, DuPont Corp., 30 μm thick) was used to seal the ESP. The penetrability of soft X-rays through the polyamide film was estimated to be around 90%.)

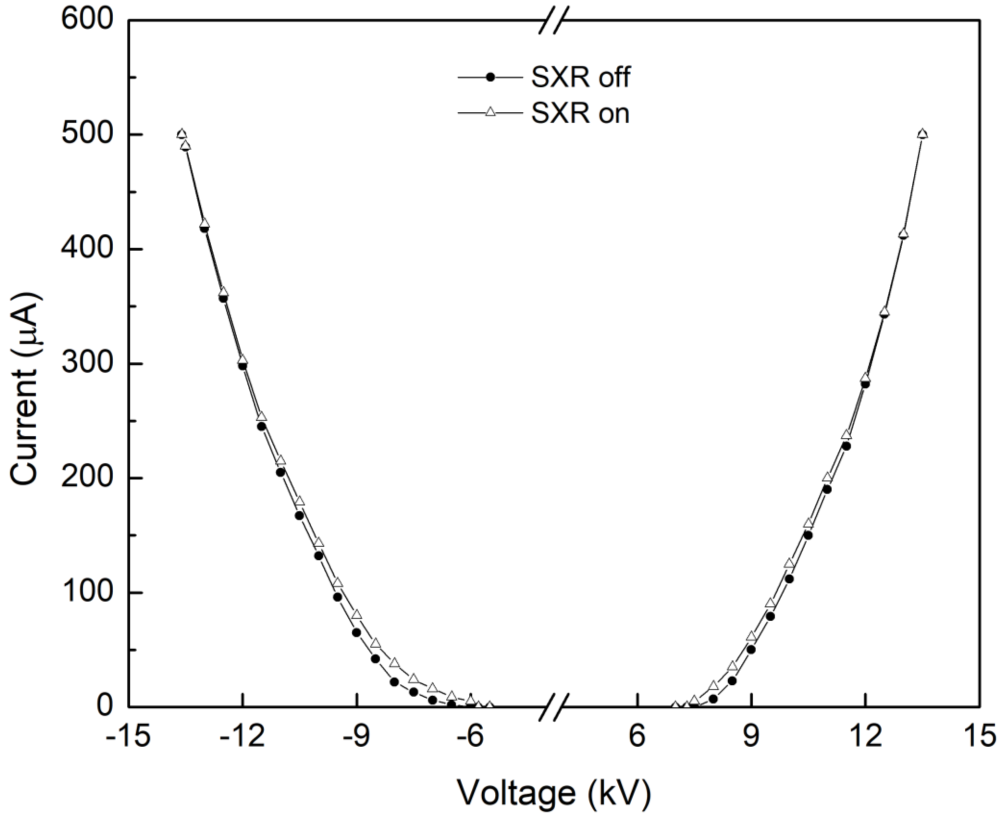


Figure S2. Current-voltage characteristics of the ESP with soft X-ray (SXR).

SXR energy requirement estimation

Assume a typical industrial ESP has a plate area of 10000 ft^2 (929 m^2) (Turner, et al., 1988). The plate area of the ESP used in this study is 0.0383 m^2. Therefore, approximately 929/0.0383=24256 ESPs used in this study are needed for industry-scale application. The maximum distance that the SXR can cover is 30 cm according to its manual, while the ESP diameter is only 5 cm. Therefore, it is assumed that the SXR can be associated with 30/5=6 ESPs in our study. Thus 24256/6=4043 SXRs used in this study are needed for the same industry-scale application. The maximum power of the SXR photoionizer is 4 W. Suppose there are 8760 hrs operation of both ESP and associated SXR in one year. Then the energy cost of industrial ESP for one year is calculated by the following equation (Turner, et al., 1988):

$$OP_{ESP} = 1.94 \times 10^{-3} A\theta = 1.94 \times 10^{-3} \times 10000 \times 8760 = 170 \times 10^{3} (kWh/yr)$$
$$= 170 (MWhs/yr)$$

where OP_{ESP} is annual ESP operating power (kWh/yr), A is ESP collecting area (ft^2) and θ is annual operating time (hr/yr).

The energy cost of the associated SXR for one year is:

$$4043 \times 4\ (W) \times 8760\ (hr/yr) = 142\ (MWhs/yr)$$

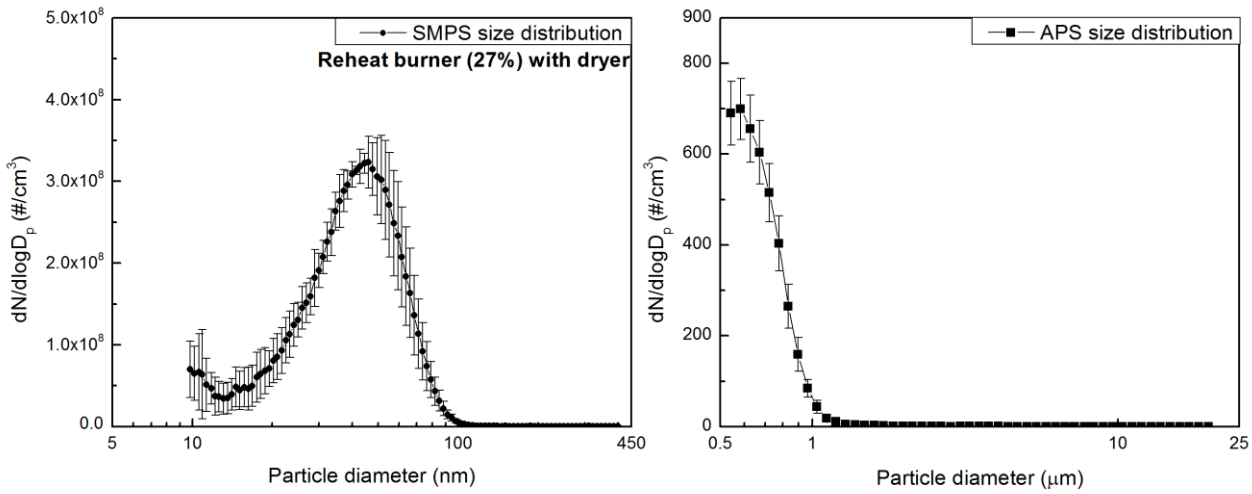
The energy requirement for SXR can be even lower if its operation duration can be cut off when the requirement of particle removal is less strict, for example while the amine scrubber is offline. Operational challenges of SXR include: (1) the SXR emitter needs to be installed in an X-ray shielded cabinet to avoid human X-ray exposure; (2) leakage monitoring procedure is needed to check the X-ray leakage around the emitter.

Reference

Turner, J. H., Lawless, P. A., Yamamoto, T., Coy, D. W., Greiner, G. P., McKenna, J. D., & Vatavuk, W. M. 1988. Sizing and Costing of Electrostatic Precipitators: Part I. Sizing Considerations. JAPCA, 38(4), 458-471. doi: 10.1080/08940630.1988.10466413

Table S1. Summary on the total number concentration (15.7–399.5 nm), $PM_{2.5}$ mass concentration and mean particle size for the tested conditions

Test #	Test condition		Diffusion dryer	Total Num. Conc. (#/cm^3)	$PM_{2.5}$ Mass Conc. (mg/m^3)	Mean size (nm)
1	Soot blow	Boiler 5 soot blow	installed	1.95×10^{10}	N/A	57.2
		Boiler 7 soot blow	installed	1.88×10^{10}	N/A	50.9
2	FGD bypass		installed	1.96×10^{10}	N/A	55.3
3	Reheat burner off (0%)		installed	2.00×10^{10}	1.65	50.3
			N/A	2.62×10^{10}	N/A	45.5
4	Reheat burner (27% of full capacity)		installed	0.85×10^{10}	1.55	48.1
5	Reheat burner (42% of full capacity, normal operation)		installed	0.90×10^{10}	N/A	40.9
			N/A	1.50×10^{10}	N/A	42.1



(a) (b)

Figure S3. Size distribution of particles with size between 10 nm to 20 μm when the reheat burner rating is 27%: (a) SMPS and (b) APS. (A diffusion dryer was used before the instruments.)