[6] In some examples, the at least one phosphonium halide comprises a compound with a formula: $P(R_1R_2R_3R_4)X$, wherein $X=I^-$, Br^-, I_3^-, BrI_2^-, Br_2I^-, or Br_3^-, and wherein at least one of R_1, R_2, R_3 or R_4 is a hydrocarbon having from 1 to 18 carbon atoms. In some examples, the hydrocarbon is chosen from an alkyl, an aryl, or a cyclic alkyl. In some examples, the at least one

phosphonium halide comprises a quaternary phosphonium iodide. In some examples, the at least one phosphonium halide comprises a quaternary phosphonium bromide. In some examples, the at least one phosphonium halide comprises a quaternary phosphonium triiodide. In some examples, the at least one phosphonium halide comprises a quaternary phosphonium tribromide. In some examples, the at least one phosphonium halide comprises ethyltriphenylphosphonium iodide (ETPPI). In some examples, the at least one phosphonium halide comprises tetrabutylphosphonium iodide (TBPI), ethyltriphenylphosphonium triiodide ($ETPPI_3$), tetrabutyl phosphonium bromide (TBPBr), ethyltriphenylphosphonium bromide (ETPPBr), or any combination thereof.

[6a] One aspect of the present disclosure relates to a device comprising: a sorbent polymer composite; wherein the sorbent polymer composite comprises: a sorbent; and a polymer; and at least one phosphonium halide, wherein the at least one phosphonium halide comprises a compound with a formula: $P(R_1R_2R_3R_4)X$, wherein $X=I^-$, Br^-, I_3^-, BrI_2^-, Br_2I^-, or Br_3^-, and wherein at least one of R_1, R_2, R_3 or R_4 is a hydrocarbon having from 1 to 18 carbon atoms, wherein the at least one phosphonium halide is: disposed on the sorbent polymer composite, disposed within the sorbent polymer composite, or any combination thereof; and wherein the device is configured to treat a flue gas stream.

[7] In some examples, the at least one phosphonium halide is thermally stable, such that the at least one phosphonium halide retains a single molecular formula, at temperatures in excess of 180°C. In some examples, the at least one phosphonium halide is thermally stable, such that the at least one phosphonium halide retains a single molecular formula, at temperatures from 180°C to 400°C. In some examples, the at least one phosphonium halide is thermally stable, such that the at least one phosphonium halide retains a single molecular formula, at temperatures from 200°C to 400°C. In some examples, the sorbent of the sorbent polymer composite has a surface area in excess of 400 m^2/g. In some examples, the sorbent of the sorbent polymer composite has a surface area ranging from 400 m^2/g to 2000 m^2/g. In some examples, the sorbent of the sorbent polymer composite is chosen from: activated carbon, silica gel, zeolites, or any combination thereof. In some examples, the polymer of the sorbent polymer composite has a surface energy of less than 31 dynes per cm. In some examples, the polymer of the sorbent polymer composite has a surface energy ranging from 15 dynes per cm to 31 dynes per cm. In some examples, the polymer of the sorbent polymer composite comprises a fluoropolymer. In some examples, the fluoropolymer is expanded polytetrafluoroethylene (ePTFE). In some examples, the at least one phosphonium halide is disposed within the sorbent polymer composite.

[8] The present disclosure also relates to a method of treating a flue gas stream. In some examples, the flue gas stream may comprise oxygen, water vapor, at least one SO_x compound, and mercury vapor. In some examples, the method may comprise passing the flue gas stream over a device, where the device comprises a sorbent polymer composite, and where the sorbent polymer composite comprises a sorbent, a polymer, and at least one phosphonium halide. In some examples, the at least one phosphonium halide is disposed on the sorbent polymer composite, disposed within the sorbent polymer composite, or any combination thereof. In some examples, the method may further comprise reacting the oxygen and water vapor with the at least one SO_x compound on the sorbent polymer composite, so as

to form sulfuric acid. In some examples, the method may further comprise reacting the mercury vapor with the at least one phosphonium halide, so as to fix molecules of the mercury vapor to the sorbent polymer composite. In some examples, the method further comprises, prior to the treating step, obtaining the flue gas stream from at least one combustion process. In some examples, the at least one SO_x compound comprises sulfur dioxide (SO_2), sulfur trioxide (SO_3), or any combination thereof.

[8a] Another aspect of the present disclosure relates to a method comprising: treating a flue gas stream, wherein the flue gas stream comprises: oxygen, water vapor, at least one SO_x compound, and mercury vapor; wherein treating the flue gas stream comprises: passing the flue gas stream over a device, wherein the device comprises: a sorbent polymer composite; wherein the sorbent polymer composite comprises: a sorbent; and a polymer; and at least one phosphonium halide, wherein the at least one phosphonium halide comprises a compound with a formula: $P(R_1R_2R_3R_4)X$, wherein $X=I^-$, Br^-, I_3^-, BrI_2^-, Br_2I^-, or Br_3^-, and wherein at least one of R_1, R_2, R_3 or R_4 is a hydrocarbon having from 1 to 18 carbon atoms, wherein the at least one phosphonium halide is: disposed on the sorbent polymer composite, disposed within the sorbent polymer composite, or any combination thereof; reacting the oxygen and water vapor with the at least one SO_x compound on the sorbent polymer composite, so as to form sulfuric acid; and reacting the mercury vapor with the at least one phosphonium halide, so as to fix molecules of the mercury vapor to the sorbent polymer composite.

DRAWINGS

[9] Some embodiments of the disclosure are herein described, by way of example only, with reference to the accompanying drawings. With specific reference now to the drawings in detail, it is stressed that the embodiments shown are by way of example and for purposes of illustrative discussion of embodiments of the disclosure. In this regard, the description taken with the drawings makes apparent to those skilled in the art how embodiments of the disclosure may be practiced.

[10] FIG. 1 is an illustration of a device, in the form of a flue gas treatment unit, according to some embodiments of the present disclosure.

[11] FIGS. 2A and 2B are simplified illustrations of sorbent polymer composites in accordance with some embodiments of the present disclosure.

[12] FIG. 3 is a chart showing Langmuir Adsorption isotherms of various exemplary phosphonium halides in accordance with some embodiments of the present disclosure.

[13] FIG. 4 is a chart showing the stability of ethyltriphenylphosphonium iodide (ETPPI) as a function of temperature in a thermal gravimetric analysis in accordance with some embodiments of the present disclosure.

CLAIMS

1. A device comprising:

a sorbent polymer composite;

wherein the sorbent polymer composite comprises:

a sorbent; and

a polymer; and

at least one phosphonium halide, wherein the at least one phosphonium halide comprises a compound with a formula: $P(R_1R_2R_3R_4)X$, wherein $X=I^-$, Br^-, I_3^-, BrI_2^-, Br_2I^-, or Br_3^-, and wherein at least one of R_1, R_2, R_3 or R_4 is a hydrocarbon having from 1 to 18 carbon atoms,

wherein the at least one phosphonium halide is:

disposed on the sorbent polymer composite,

disposed within the sorbent polymer composite, or

any combination thereof; and

wherein the device is configured to treat a flue gas stream.

2. The device of claim 1, wherein the hydrocarbon is chosen from an alkyl, an aryl, or a cyclic alkyl.

3. The device of claim 1 or 2, wherein the at least one phosphonium halide comprises a quaternary phosphonium iodide.

4. The device of any of the preceding claims, wherein the at least one phosphonium halide comprises a quaternary phosphonium bromide.

5. The device of any of the preceding claims, wherein the at least one phosphonium halide comprises a quaternary phosphonium triiodide.

6. The device of any of the preceding claims, wherein the at least one phosphonium halide comprises a quaternary phosphonium tribromide.

7. The device of any of the preceding claims, wherein the at least one phosphonium halide comprises ethyltriphenylphosphonium iodide (ETPPI).

8. The device of any of the preceding claims, wherein the at least one phosphonium halide comprises tetrabutylphosphonium iodide (TBPI), ethyltriphenylphosphonium triiodide ($ETPPI_3$), tetrabutyl phosphonium bromide (TBPBr), ethyltriphenylphosphonium bromide (ETPPBr), or any combination thereof.

9. The device of any of the preceding claims, wherein the at least one phosphonium halide is thermally stable, such that the at least one phosphonium halide retains a single molecular formula, at temperatures in excess of 180°C.

10. The device of Claim 9, wherein the at least one phosphonium halide is thermally stable, such that the at least one phosphonium halide retains a single molecular formula, at temperatures from 180°C to 400°C.

11. The device of Claim 10, wherein the at least one phosphonium halide is thermally stable, such that the at least one phosphonium halide retains a single molecular formula, at temperatures from 200°C to 400°C.

12. The device of any of the preceding claims, wherein the sorbent of the sorbent polymer composite has a surface area in excess of 400 m^2/g.

13. The device of claim 12, wherein the sorbent of the sorbent polymer composite has a surface area ranging from 400 m^2/g to 2000 m^2/g.

14. The device of any of the preceding claims, wherein the sorbent of the sorbent polymer composite is chosen from: activated carbon, silica gel, zeolites, or any combination thereof.

15. The device of any of the preceding claims, wherein the polymer of the sorbent polymer composite has a surface energy of less than 31 dynes per cm.

16. The device of claim 15, wherein the polymer of the sorbent polymer composite has a surface energy ranging from 15 dynes per cm to 31 dynes per cm.

17. The device of any of the preceding claims, wherein the polymer of the sorbent polymer composite comprises a fluoropolymer.

18. The device of claim 17, wherein the fluoropolymer is expanded polytetrafluoroethylene (ePTFE).

19. A method comprising:

treating a flue gas stream,

wherein the flue gas stream comprises:

oxygen,

water vapor,

at least one SO_x compound, and

mercury vapor;

wherein treating the flue gas stream comprises:

passing the flue gas stream over a device,

wherein the device comprises:

a sorbent polymer composite;

wherein the sorbent polymer composite comprises:

a sorbent; and

a polymer; and

at least one phosphonium halide, wherein the at least one phosphonium halide comprises a compound with a formula: $P(R_1R_2R_3R_4)X$, wherein $X=I^-$, Br^-, I_3^-, BrI_2^-, Br_2I^-, or Br_3^-, and wherein at least one of R_1, R_2, R_3 or R_4 is a hydrocarbon having from 1 to 18 carbon atoms,

wherein the at least one phosphonium halide is: disposed on the sorbent polymer composite, disposed within the sorbent polymer composite, or any combination thereof;

reacting the oxygen and water vapor with the at least one SO_x compound on the sorbent polymer composite, so as to form sulfuric acid; and

reacting the mercury vapor with the at least one phosphonium halide, so as to fix molecules of the mercury vapor to the sorbent polymer composite.

20. The method of claim 19, further comprising, prior to the treating step, obtaining the flue gas stream from at least one combustion process.

21. The method of any of claims 19 to 20, wherein the at least one SO_x compound comprises sulfur dioxide (SO_2), sulfur trioxide (SO_3), or any combination thereof.

22. The device of any of claims 1-18, wherein the at least one phosphonium halide is disposed within the sorbent polymer composite.