IMPROVING CATALYTIC EFFICIENCY OF FLUE GAS FILTRATION THROUGH SALT FORMATION BY USING AT LEAST ONE OXIDIZING AGENT

CROSS-REFERENCE TO RELATED APPLICATIONS

[001] The present application claims priority to and benefit of U.S. Provisional Patent Application No. 63/132289, filed December 30, 2020, and entitled “IMPROVING CATALYTIC EFFICIENCY OF FLUE GAS FILTRATION THROUGH SALT FORMATION BY USING AT LEAST ONE OXIDIZING AGENT,” the entirety of which is herein incorporated by reference.

FIELD

[002] The present disclosure relates to the field of a filter medium, and methods and systems for using the same to filter a flue gas stream.

BACKGROUND

[003] Coal-fired power generation plants, municipal waste incinerators, and oil refinery plants generate large amounts of flue gases that contain substantial varieties and quantities of environmental pollutants, nitrogen oxides (NOx compounds), mercury (Hg) vapor, sulfur oxides and particulate matters (PM). In the United States, burning coal alone generates about 27 million tons of SO_2 and 45 tons of Hg each year. Thus, there is a need for improvements to methods for removing NOx compounds, sulfur oxides (SO_2), mercury vapor, and fine particulate matters from industrial flue gases, such as coal-fired power plant flue gas.

SUMMARY

[004] The present disclosure provides a method comprising: obtaining at least one filter medium; wherein the at least one filter medium comprises at least one catalyst material; flowing a flue gas stream transverse to a cross section of the at least one filter medium, such that the flue gas stream passes through the cross section of the at least one filter medium, wherein the flue gas stream comprises sulfur dioxide (SO_2); and increasing a SO_2 removal efficiency of the at least one filter medium, wherein increasing the SO_2 removal efficiency of the at least one filter medium comprises: introducing at least one oxidizing agent into the flue gas stream, so as to react at least some of the SO_2 with the at least one oxidizing agent to form sulfur trioxide (SO_3), sulfuric acid (H_2SO_4), or

any combination thereof; and introducing ammonia (NH_3) into the flue gas stream, so as to react at least some of the sulfur trioxide (SO_3), at least some of the sulfuric acid (H_2SO_4), or any combination thereof, with the ammonia (NH_3) and form at least one salt.

[004a] In an aspect, the present disclosure provides a method comprising: obtaining at least one filter medium; wherein the at least one filter medium comprises at least one catalyst material; a porous protective layer; and a porous catalytic layer comprising a plurality of perforations, flowing a flue gas stream transverse to a cross section of the at least one filter medium, such that the flue gas stream passes through the cross section of the at least one filter medium, wherein the flue gas stream comprises sulfur dioxide (SO_2); and increasing a SO_2 removal efficiency of the at least one filter medium, wherein increasing the SO_2 removal efficiency of the at least one filter medium comprises: introducing at least one oxidizing agent into the flue gas stream, so as to react at least some of the SO_2 with the at least one oxidizing agent to form sulfur trioxide (SO_3), sulfuric acid (H_2SO_4), or any combination thereof; and introducing ammonia (NH_3) into the flue gas stream, so as to react at least some of the sulfur trioxide (SO_3), at least some of the sulfuric acid (H_2SO_4), or any combination thereof, with the ammonia (NH_3) and form at least one salt.

[005] In some examples of the method, the SO_2 removal efficiency of the at least one filter medium is increased from 0.1% to 99.9% relative to an initial SO_2 removal efficiency of the at least one filter medium.

[006] In some examples of the method, the flue gas stream further comprises NOx compounds comprising nitric oxide (NO); and nitrogen dioxide (NO_2), wherein introducing the at least one oxidizing agent into the flue gas stream increases a NO_2 concentration to a range from 2% to 99% of a total concentration of the NOx compounds, and wherein increasing the NO_2 concentration increases NOx removal efficiency of the at least one filter medium.

[007] In some examples of the method, the at least one oxidizing agent comprises hydrogen peroxide (H_2O_2), ozone (O_3), hydroxyl radical, at least one organic peroxide, at least one metal peroxide, at least one peroxy-acid, at least one percarbonate salt, at least one perborate salt, at least one persulfate salt, at least one permanganate salt, at least one hypochlorite salt, chlorine dioxide (ClO_2), at least one chlorate salt, at least one perchlorate salt, at least one hypochlorite salt, perchloric acid ($HClO_4$), at least one

bismuthate salt, any aqueous solution comprising at least one of the foregoing, or any combination thereof.

[008] In some examples of the method, the at least one oxidizing agent is H_2O_2 or an aqueous solution thereof.

[009] In some examples, the method further comprises introducing at least one dry sorbent into the flue gas stream so as to react at least some of the sulfur trioxide (SO_3), at least some of the sulfuric acid (H_2SO_4), or any combination thereof, with the at least one dry sorbent and form at least one salt.

[0010] In some examples of the method, the flue gas stream further comprises oxygen (O_2), water (H_2O), nitrogen (N_2), sulfur trioxide (SO_3), carbon monoxide (CO), at least one hydrocarbon, ammonia (NH_3), or any combination thereof.

[0011] In some examples of the method, the NH_3 is introduced into the flue gas stream in a concentration ranging from 0.0001% to 0.5% of the concentration of the flue gas stream.

one salt from the at least one filter medium comprises removing the at least one salt from the porous protective layer of the at least one filter medium.

[0023] In some examples of the method, the at least one salt comprises ammonium sulfate (AS) ammonium bisulfate (ABS), triammonium hydrogen disulfate (A_3HS_2), ammonium sulfamate (ASM), or any combination thereof.

[0024] In some examples of the method, introducing the NH_3 into the flue gas stream is performed after introducing the at least one oxidizing agent into the flue gas stream.

[0025] In some examples of the method, introducing the NH_3 into the flue gas stream is performed before introducing the at least one oxidizing agent into the flue gas stream, during the introducing of the at least one oxidizing agent into the flue gas stream, or any combination thereof.

[0026] In some examples of the method, introducing the at least one dry sorbent into the flue gas stream is performed after introducing the at least one oxidizing agent into the flue gas stream.

[0027] In some examples of the method, introducing the at least one dry sorbent into the flue gas stream is performed before introducing the at least one oxidizing agent into the flue gas stream, during the introducing of the at least one oxidizing agent into the flue gas stream, or any combination thereof.

[0028] The present disclosure also provides a method comprising: obtaining at least one filter medium, wherein the at least one filter medium comprises at least one catalyst material; flowing a flue gas stream transverse to a cross section of the at least one filter medium, such that the flue gas stream passes through the cross section of the at least one filter medium, wherein the flue gas stream comprises sulfur dioxide (SO_2); and increasing a SO_2 removal efficiency of the at least one filter medium, wherein increasing the SO_2 removal efficiency of the at least one filter medium comprises: introducing at least one oxidizing agent into the flue gas stream, so as to react at least some of the SO_2 with the at least one oxidizing agent to form sulfur trioxide (SO_3), sulfuric acid (H_2SO_4), or any combination thereof; and introducing at least one dry sorbent into the flue gas stream, so as to react at least some of the sulfur trioxide (SO_3), at least some of the sulfuric acid (H_2SO_4), or any combination thereof, with the at least one dry sorbent and form at least one salt.

[0028a] In another aspect, the present disclosure provides a method comprising: obtaining at least one filter medium, wherein the at least one filter medium comprises at least one catalyst material; a porous protective layer; and a porous catalytic layer comprising a plurality of perforations, flowing a flue gas stream transverse to a cross section of the at least one filter medium, such that the flue gas stream passes through the cross section of the at least one

filter medium, wherein the flue gas stream comprises sulfur dioxide (SO_2); and increasing a SO_2 removal efficiency of the at least one filter medium, wherein increasing the SO_2 removal efficiency of the at least one filter medium comprises: introducing at least one oxidizing agent into the flue gas stream, so as to react at least some of the SO_2 with the at least one oxidizing agent to form sulfur trioxide (SO_3), sulfuric acid (H_2SO_4), or any combination thereof; and introducing at least one dry sorbent into the flue gas stream, so as to react at least some of the sulfur trioxide (SO_3), at least some of the sulfuric acid (H_2SO_4), or any combination thereof, with the at least one dry sorbent and form at least one salt.

[0029] In some examples, the method further comprises introducing ammonia (NH_3) into the flue gas stream, so as to react at least some of the sulfur trioxide (SO_3),

at least some of the sulfuric acid (H_2SO_4), or any combination thereof, with the ammonia (NH_3) and form at least one salt.

[0030] In some examples of the method, increasing the SO_2 removal efficiency of the at least one filter medium comprises introducing at least one oxidizing agent into the flue gas stream, so as to react at least 1 ppm of the SO_2 with the at least one oxidizing agent to form sulfur trioxide (SO_3), sulfuric acid (H_2SO_4), or any combination thereof; and introducing ammonia (NH_3) into the flue gas stream, so as to react at least 1 ppm of the sulfur trioxide (SO_3), at least 1ppm of the sulfuric acid (H_2SO_4), or any combination thereof, with the ammonia (NH_3) and form at least one salt.

[0031] In some examples of the method, ammonia (NH_3) is introduced into the flue gas stream in a concentration ratio of NH_3 to NOx compounds of 7:200 to 9:5.

[0032] The present disclosure also provides a system comprising: at least one filter medium, wherein the at least one filter medium comprises: an upstream side; a downstream side; at least one catalyst material; at least one filter bag, wherein the at least one filter medium is disposed within the at least one filter bag; and at least one filter bag housing, wherein the at least one filter bag is disposed within the at least one filter bag housing; wherein the at least one filter bag housing is configured to receive a flow of a flue gas stream transverse to a cross section of the at least one filter medium, such that the flue gas stream passes through the cross section of the at least one filter medium from the upstream side of the at least one filter medium to the downstream side of the at least one filter medium, wherein the flue gas stream comprises sulfur dioxide (SO_2), wherein the system is configured to increase a SOx removal efficiency of the at least one filter medium upon: introduction of at least one oxidizing agent into the flue gas stream; and introduction of ammonia (NH_3) into the flue gas stream.

[0032a] In another aspect, the present disclosure provides a system comprising: at least one filter medium, wherein the at least one filter medium comprises: an upstream side; a downstream side; at least one catalyst material; a porous protective layer; and a porous catalytic layer comprising a plurality of perforations, at least one filter bag, wherein the at least one filter medium is disposed within the at least one filter bag; and at least one filter bag housing, wherein the at least one filter bag is disposed within the at least one filter bag housing; wherein the at least one filter bag housing is configured to receive a flow of a flue gas stream transverse to a cross section of the at least one filter medium, such that the flue gas stream passes through the cross section of the at least one filter medium from the upstream side of the at least one filter medium to the downstream side of the at least one filter medium, wherein the flue gas stream comprises sulfur dioxide (SO_2), wherein the system

is configured to increase a SOx removal efficiency of the at least one filter medium upon: introduction of at least one oxidizing agent into the flue gas stream; and introduction of ammonia (NH_3) into the flue gas stream.

[0033] In some examples of the system, the system is configured to further increase a SOx removal efficiency of the at least one filter medium upon introduction of at least one dry sorbent into the flue gas stream.

[0034] The present disclosure also provides a system comprising: at least one filter medium, wherein the at least one filter medium comprises: an upstream side; a downstream side; at least one catalyst material; at least one filter bag, wherein the at least one filter medium is disposed within the at least one filter bag; and at least one filter bag housing, wherein the at least one filter bag is disposed within the at least one filter bag housing; wherein the at least one filter bag housing is configured to receive a flow of a flue gas stream transverse to a cross section of the at least one filter medium, such that the flue gas

stream passes through the cross section of the at least one filter medium from the upstream side of the at least one filter medium to the downstream side of the at least one filter medium, wherein the flue gas stream comprises sulfur dioxide (SO_2), wherein the system is configured to increase a SOx removal efficiency of the at least one filter medium upon: introduction of at least one oxidizing agent into the flue gas stream; and introduction of at least one dry sorbent into the flue gas stream.

[0034a] In another aspect, the present disclosure provides a system comprising: at least one filter medium, wherein the at least one filter medium comprises: an upstream side; a downstream side; at least one catalyst material; a porous protective layer; and a porous catalytic layer comprising a plurality of perforations, at least one filter bag, wherein the at least one filter medium is disposed within the at least one filter bag; and at least one filter bag housing, wherein the at least one filter bag is disposed within the at least one filter bag housing; wherein the at least one filter bag housing is configured to receive a flow of a flue gas stream transverse to a cross section of the at least one filter medium, such that the flue gas stream passes through the cross section of the at least one filter medium from the upstream side of the at least one filter medium to the downstream side of the at least one filter medium, wherein the flue gas stream comprises sulfur dioxide (SO_2), wherein the system is configured to increase a SOx removal efficiency of the at least one filter medium upon: introduction of at least one oxidizing agent into the flue gas stream; and introduction of at least one dry sorbent into the flue gas stream.

[0035] In some examples of the system, the system is configured to further increase a SOx removal efficiency of the at least one filter medium upon introduction of NH_3 into the flue gas stream.

DRAWINGS

[0036] 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.

[0037] 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.

[0038] Figure 1A depicts an exemplary system with a filter bag comprising a filter medium according to some embodiments of the present disclosure.

[0039] Figure 1B depicts a filter medium according to some embodiments of the present disclosure.

[0040] Figure 1C depicts a porous catalytic layer according to some embodiments of the present disclosure.

[0041] Figure 2 depicts an exemplary SO_2 concentration change upon 1 wt% H_2O_2 injection according to some embodiments of the present disclosure.

[0042] Figure 3 depicts an exemplary NO and NO_2 concentration change upon 1 wt% H_2O_2 injection according to some embodiments of the present disclosure.

CLAIMS

What is claimed is:

1. A method comprising:

obtaining at least one filter medium;

wherein the at least one filter medium comprises at least one catalyst material;

a porous protective layer; and

a porous catalytic layer comprising a plurality of perforations,

flowing a flue gas stream transverse to a cross section of the at least one filter medium, such that the flue gas stream passes through the cross section of the at least one filter medium,

wherein the flue gas stream comprises sulfur dioxide (SO_2); and

increasing a SO_2 removal efficiency of the at least one filter medium,

wherein increasing the SO_2 removal efficiency of the at least one filter medium comprises:

introducing at least one oxidizing agent into the flue gas stream, so as to react at least some of the SO_2 with the at least one oxidizing agent to form sulfur trioxide (SO_3), sulfuric acid (H_2SO_4), or any combination thereof; and

introducing ammonia (NH_3) into the flue gas stream, so as to react at least some of the sulfur trioxide (SO_3), at least some of the sulfuric acid (H_2SO_4), or any combination thereof, with the ammonia (NH_3) and form at least one salt.

2. The method of claim 1, wherein the SO_2 removal efficiency of the at least one filter medium is increased from 0.1% to 99.9% relative to an initial SO_2 removal efficiency of the at least one filter medium.

3. The method of claim 1 or claim 2 wherein the flue gas stream further comprises:

NOx compounds comprising:

nitric oxide (NO); and

nitrogen dioxide (NO_2),

wherein introducing the at least one oxidizing agent into the flue gas stream increases a NO_2 concentration to a range from 2% to 99% of a total concentration of the NOx compounds, and wherein increasing the

NO_2 concentration increases NOx removal efficiency of the at least one filter medium.

4. The method of any of claims 1 to 3, wherein the at least one oxidizing agent comprises:

hydrogen peroxide (H_2O_2), ozone (O_3), hydroxyl radical, at least one organic peroxide, at least one metal peroxide, at least one peroxy-acid, at least one percarbonate salt, at least one perborate salt, at least one persulfate salt, at least one permanganate salt, at least one hypochlorite salt, chlorine dioxide (ClO_2), at least one chlorate salt, at least one perchlorate salt, at least one hypochlorite salt, perchloric acid ($HClO_4$), at least one bismuthate salt, any aqueous solution comprising at least one of the foregoing, or any combination thereof.

5. The method of claim 4, wherein the at least one oxidizing agent is H_2O_2 or an aqueous solution thereof.

6. The method of any of claims 1 to 5, further comprising:

introducing at least one dry sorbent into the flue gas stream so as to react at least some of the sulfur trioxide (SO_3), at least some of the sulfuric acid (H_2SO_4), or any combination thereof, with the at least one dry sorbent and form at least one salt.

7. The method of any of claims 1 to 6, wherein the flue gas stream further comprises oxygen (O_2), water (H_2O), nitrogen (N_2), sulfur trioxide (SO_3), carbon monoxide (CO), at least one hydrocarbon, ammonia (NH_3), or any combination thereof.

8. The method of any of claims 1 to 7, wherein the NH_3 is introduced into the flue gas stream in a concentration ranging from 0.0001% to 0.5% of the concentration of the flue gas stream.

9. The method of any of claims 1 to 8, wherein the at least one oxidizing agent is introduced into the flue gas stream in a sufficient amount to convert at least 5% of the SO_2 in the flue gas stream, to SO_3, H_2SO_4, the at least one salt, or any combination thereof.

10. The method of claim 9, wherein the sufficient amount of the at least one oxidizing agent that is introduced into the flue gas stream is 0.001 wt% to 90 wt% based on a total weight of the at least one oxidizing agent in water.

11. The method of claim 9, wherein the sufficient amount of the at least one oxidizing agent that is introduced into the flue gas stream is 5 ppm to 10000 ppm of the flue gas stream.

12. The method of claim 9, wherein the sufficient amount of the at least one oxidizing agent that is introduced into the flue gas stream is a concentration ratio of the at least one oxidizing agent to SO_2 of 1:10 to 20:1.

13. The method of any of claims 1 to 12, wherein a temperature of the flue gas stream ranges from 100 °C to 300 °C at least during the flowing of the flue gas stream transverse to a cross section of the at least one filter medium.

14. The method of any of claims 7 to 13, wherein the water is present the flue gas stream in an amount ranging from 0.1 vol% to 50 vol% based on a total volume of the flue gas stream at least during the flowing of the flue gas stream transverse to a cross section of the at least one filter medium.

15. The method of any of claims 1 to 14, wherein the SO_2 is present in the flue gas stream in an amount from 0.01 ppm to 1000 ppm at least during the flowing of the flue gas stream transverse to a cross section of the at least one filter medium.

16. The method of any of claims 3 to 15, wherein the NOx compounds are present in the flue gas stream in an amount from 0.1 ppm to 5000 ppm at least during the flowing of the flue gas stream transverse to a cross section of the at least one filter medium.

17. The method of any of claims 6 to 16, wherein the at least one dry sorbent comprises sodium bicarbonate, trona, calcium hydroxide, calcium carbonate, calcium oxide, cement dust, lime, or any combination thereof.

18. The method of any of claims 1 to 17, further comprising removing the at least one salt from the at least one filter medium.

19. The method of claim 18, wherein removing the at least one salt from the at least one filter medium comprises removing the at least one salt from the porous protective layer of the at least one filter medium.

20. The method of any of claims 1 to 19, wherein the at least one salt comprises ammonium sulfate (AS) ammonium bisulfate (ABS), triammonium hydrogen disulfate (A_3HS_2), ammonium sulfamate (ASM), or any combination thereof.

21. The method of any of claims 1 to 20, wherein introducing the NH_3, into the flue gas stream is performed after introducing the at least one oxidizing agent into the flue gas stream.

22. The method of any of claims 1 to 21, wherein introducing the NH_3 into the flue gas stream is performed before introducing the at least one oxidizing agent into the flue gas stream, during the introducing of the at least one oxidizing agent into the flue gas stream, or any combination thereof.

23. The method of any of claims 6 to 22, wherein introducing the at least one dry sorbent into the flue gas stream is performed after introducing the at least one oxidizing agent into the flue gas stream.

24. The method of any of claims 6 to 23, wherein introducing the at least one dry sorbent into the flue gas stream is performed before introducing the at least one oxidizing agent into the flue gas stream, during the introducing of the at least one oxidizing agent into the flue gas stream, or any combination thereof.

25. A method comprising:

obtaining at least one filter medium,

wherein the at least one filter medium comprises at least one catalyst material;

a porous protective layer; and

a porous catalytic layer comprising a plurality of perforations,

flowing a flue gas stream transverse to a cross section of the at least one filter medium, such that the flue gas stream passes through the cross section of the at least one filter medium,

wherein the flue gas stream comprises sulfur dioxide (SO_2); and

increasing a SO_2 removal efficiency of the at least one filter medium,

wherein increasing the SO_2 removal efficiency of the at least one filter medium comprises:

introducing at least one oxidizing agent into the flue gas stream, so as to react at least some of the SO_2 with the at least one oxidizing agent to form sulfur trioxide (SO_3), sulfuric acid (H_2SO_4), or any combination thereof; and

introducing at least one dry sorbent into the flue gas stream, so as to react at least some of the sulfur trioxide (SO_3), at least some of the sulfuric acid (H_2SO_4), or any combination thereof, with the at least one dry sorbent and form at least one salt.

26. The method of claim 25, further comprising:

introducing ammonia (NH_3) into the flue gas stream, so as to react at least some of the sulfur trioxide (SO_3), at least some of the sulfuric acid (H_2SO_4), or any combination thereof, with the ammonia (NH_3) and form at least one salt.

27. The method of any of claims 1 to 26, wherein increasing the SO_2 removal efficiency of the at least one filter medium comprises:

introducing at least one oxidizing agent into the flue gas stream, so as to react at least 1 ppm of the SO_2 with the at least one oxidizing agent to form sulfur trioxide (SO_3), sulfuric acid (H_2SO_4), or any combination thereof; and

introducing ammonia (NH_3) into the flue gas stream, so as to react at least 1 ppm of the sulfur trioxide (SO_3), at least 1ppm of the sulfuric acid (H_2SO_4), or any combination thereof, with the ammonia (NH_3) and form at least one salt.

28. The method of any of claims 1 to 27, wherein ammonia (NH_3) is introduced into the flue gas stream in a concentration ratio of NH_3 to NOx compounds of 7:200 to 9:5.

29. A system comprising:

at least one filter medium,

wherein the at least one filter medium comprises:

an upstream side;

a downstream side;

at least one catalyst material;

a porous protective layer; and

a porous catalytic layer comprising a plurality of perforations,

at least one filter bag,

wherein the at least one filter medium is disposed within the at least one filter bag; and

at least one filter bag housing,

wherein the at least one filter bag is disposed within the at least one filter bag housing;

wherein the at least one filter bag housing is configured to receive a flow of a flue gas stream transverse to a cross section of the at least one filter medium, such that the flue gas stream passes through the cross section of the at least one filter medium from the upstream side of the at least one filter medium to the downstream side of the at least one filter medium,

wherein the flue gas stream comprises sulfur dioxide (SO_2),

wherein the system is configured to increase a SOx removal efficiency of the at least one filter medium upon:

introduction of at least one oxidizing agent into the flue gas stream; and

introduction of ammonia (NH_3) into the flue gas stream.

30. The system of claim 29, wherein the system is configured to further increase a SOx removal efficiency of the at least one filter medium upon introduction of at least one dry sorbent into the flue gas stream.

31. A system comprising:

at least one filter medium,

wherein the at least one filter medium comprises:

an upstream side;

a downstream side;

at least one catalyst material;

a porous protective layer; and

a porous catalytic layer comprising a plurality of perforations,

at least one filter bag,

wherein the at least one filter medium is disposed within the at least one filter bag; and

at least one filter bag housing,

wherein the at least one filter bag is disposed within the at least one filter bag housing;

wherein the at least one filter bag housing is configured to receive a flow of a flue gas stream transverse to a cross section of the at least one filter medium, such that the flue gas stream passes through the cross section of the at least one filter medium from the upstream side of the at least one filter medium to the downstream side of the at least one filter medium,

wherein the flue gas stream comprises sulfur dioxide (SO_2),

wherein the system is configured to increase a SOx removal efficiency of the at least one filter medium upon:

introduction of at least one oxidizing agent into the flue gas stream; and

introduction of at least one dry sorbent into the flue gas stream.

32. The system of claim 31, wherein the system is configured to further increase a SOx removal efficiency of the at least one filter medium upon introduction of NH_3 into the flue gas stream.