peritoneal membrane and into the dialysis fluid during a specified dwell time via diffusion and osmosis. Spent dialysis fluid is then drained from the patient's peritoneal cavity to remove the waste, toxins, and water from the patient. The treatment can be repeated several times during the day or overnight, or both, to achieve the desired level of waste, toxin, and excess water removal.

[0006] During dialysis treatments, sorbents can be used to remove waste from the spent dialysis fluid, thereby regenerating the spent dialysis fluid for reuse. Dialysate regeneration advantageously reduces the overall volume of dialysis solution required for dialysis treatment. Sorbent materials include zirconium phosphate and zirconium oxide as ion exchange sorbents to remove cationic and/or anionic waste, and are disclosed, for example, in U.S. Patent Publication No. 2014/0001112. Other sorbent materials include a zirconium-glyoxal complex coated on activated carbon as described in U.S. Patent Publication No. 2014/0336568.

SUMMARY

[0007] In light of the disclosure herein, and without limiting the scope of the disclosure in any way, in one example of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, the disclosure provides a sorbent comprising titanium-glyoxal complex and a porous support material such as activated carbon.

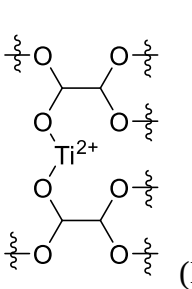
[0007a] In one aspect, the disclosure provides a sorbent comprising a titanium-glyoxal complex and a porous support material, wherein the porous support material comprises at least one of activated carbon, graphene, graphene oxide, silicon, or porous silicon.

[0008] In another example of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, the porous support material comprises activated carbon, graphene, graphene oxide, silicon, porous silicon, or a combination thereof.

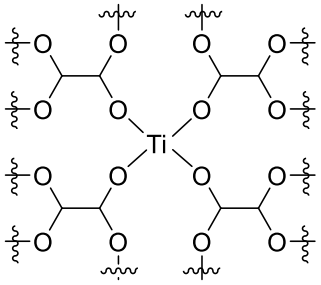
[0009] In another example of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, the titanium-glyoxal complex comprises titanium-crosslinked hydrated glyoxal moieties.

[0010] In another example of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, the titanium-glyoxal complex is formed by reacting hydrated glyoxal with titanium ions.

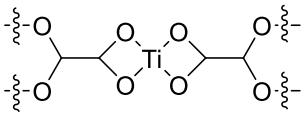
[0011] In another example of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, the titanium-glyoxal complex has a structure comprising a molecule of formula I, formula II, formula III, formula IV, or a combination thereof:



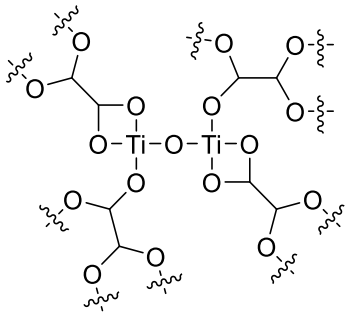
(I),



(II),



(III), or



(IV).

[0012] In another example of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, the titanium-glyoxal complex is associated with, adhered to, adsorbed on, coated on, and/or immobilized on the porous support material such as activated carbon.

[0013] In another example of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, the titanium-glyoxal complex is present in pores of the porous support material such as activated carbon.

[0014] In another example of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, the sorbent has urea capacity of greater than about 50 mg urea/g sorbent, such as greater than about 60 mg/g, greater than about 70 mg/g, greater than about 75 mg/g, greater than about 80 mg/g, greater than about 90 mg/g, about 50 mg/g to about 200 mg/g, about 50 mg/g to about 150 mg/g, about 50 mg/g to about 100 mg/g, about 60 mg/g to about 100 mg/g, about 70 mg/g to about 90 mg/g, about 75 mg/g to about 85 mg/g, and/or about 80 mg/g.

[0015] In another example of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, the molar ratio of titanium to glyoxal is about 1:4.

[0016] In another aspect of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, the disclosure provides a sorbent cartridge comprising a sorbent according to any other example listed herein.

[0017] In another example of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, the sorbent cartridge is free of an immobilized urease layer.

[0018] In another example of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, total content of active urease in the sorbent cartridge is less than about 5 wt. % based on total immobilized weight portion of cartridge contents.

[0019] In another example of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, the sorbent cartridge further comprises dialysate fluid which communicates with the sorbent. In an example of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, the dialysate fluid has a pH of about 5 to about 9, such as about 5.5 to about 8.5, about 6 to about 8, about 6.1 to about 7.9, about 6.2 to about 7.8, about 6.3 to about 7.7, about 6.4 to about 7.6, about 6.5 to about 7.5, about 6.6 to about 7.4, about 6.7 to about 7.3, about 6.8 to about 7.2, about 6.9 to about 7.1, and/or about 7.

[0020] In another example of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, the sorbent cartridge further comprises a layer comprising titanium oxide, hydrous titanium dioxide, and/or titanium phosphate.

[0021] In another aspect of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, the disclosure provides a method comprising passing a fluid comprising urea though the sorbent according to any other example listed herein and/or though the sorbent cartridge according to any other example listed herein, thereby binding urea to the titanium-glyoxal complex. In an example of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, the fluid comprising urea is a spent dialysis fluid. In an example of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, the fluid comprising urea has a pH of about 5 to about 9, such as about 5.5 to about 8.5, about 6 to about 8, about 6.1 to about 7.9, about 6.2 to about 7.8, about 6.3 to about 7.7, about 6.4 to about 7.6, about

6.5 to about 7.5, about 6.6 to about 7.4, about 6.7 to about 7.3, about 6.8 to about 7.2, about 6.9 to about 7.1, and/or about 7.

[0022] In another aspect of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, the disclosure provides an apparatus for conducting dialysis comprising the sorbent cartridge according to any other example listed herein, and a dialyzer in fluid communication with the sorbent cartridge, wherein spent dialysis fluid passes from the dialyzer to and through the sorbent cartridge. In an example of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, the spent dialysis fluid is spent hemodialysis fluid or spent peritoneal dialysis fluid.

[0023] In another example of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, the dialyzer is in fluid communication with the blood of a patient.

[0024] In another aspect of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, the disclosure provides a dialysis system comprising the sorbent cartridge of any other example listed herein and a source of spent dialysis fluid, wherein the source of spent dialysis fluid is in fluid communication with the sorbent cartridge and the spent dialysis fluid passes to and through the sorbent cartridge. In an example of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, the spent dialysis fluid is spent hemodialysis fluid or spent peritoneal dialysis fluid.

[0025] In another example of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, the disclosure provides a method of making a sorbent for binding urea, comprising: (i) combining glyoxal, a titanium ion source, and a solvent to provide a mixture comprising a titanium-glyoxal complex; (ii) adding a porous support material to the mixture to provide a treated support material; (iii) separating the solvent from the treated support material; (iv) washing the treated support material to provide a washed treated support material; and (v) drying the washed treated support material to provide a sorbent for binding urea. In an example of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, the porous support material comprises

activated carbon, graphene, graphene oxide, silicon, porous silicon, or a combination thereof. In an example of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, the disclosure provides a method of making a sorbent for binding urea, comprising: (i) combining glyoxal, a titanium ion source, and a solvent to provide a mixture comprising a titanium-glyoxal complex; (ii) adding activated carbon to the mixture to provide a treated activated carbon; (iii) separating the solvent from the treated activated carbon; (iv) washing the treated activated carbon to provide a washed treated activated carbon; and (v) drying the washed treated activated carbon to provide a sorbent for binding urea. In an example of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, the drying step is carried out at a temperature of at least 25°C, such as at least 30°C, at least 35°C, at least 40°C, about 25°C to about 40°C, about 30°C to about 40°C, about 35°C to about 40°C, and/or about 37°C.

[0025a] In another aspect, the disclosure provides a method of making a sorbent for binding urea, comprising: (i) combining glyoxal, a titanium ion source, and a solvent to provide a mixture comprising a titanium-glyoxal complex; (ii) adding activated carbon to the mixture to provide a treated activated carbon; (iii) separating the solvent from the treated activated carbon; (iv) washing the treated activated carbon to provide a washed treated activated carbon; and (v) drying the washed treated activated carbon to provide a sorbent for binding urea.

[0026] In another example of the present disclosure, which may be combined with any other example listed herein unless specified otherwise, the titanium ion source is selected from the group consisting of titanium tetrachloride, titanium (II) chloride, titanium (III) chloride, titanium oxychloride, and combinations thereof.

[0027] In light of the disclosure and examples set forth herein, it is accordingly an advantage of the present disclosure to provide sorbents, sorbent cartridges, methods, and systems for dialysis processes that reduce or avoid generation of ammonia during urea removal.

[0028] It is another advantage of the present disclosure to efficiently adsorb urea at or near a physiological pH, eliminating the need to adjust the pH of the spent dialysis fluid before exposure to the sorbent material and of the purified or regenerated dialysate after exposure to the sorbent material.

[0029] Additional features and advantages of the disclosed formulations are described in, and will be apparent from, the following Detailed Description and the figure. The features and advantages described herein are not all-inclusive and, in particular, many additional features and advantages will be apparent to one of ordinary skill in the art in view of the description. Also, any particular example does not necessarily have to have all of the advantages listed herein. Moreover, it should be noted that the language used in the specification has been principally

WHAT IS CLAMED IS:

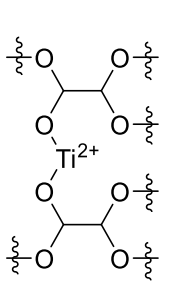
Claim 1: A sorbent comprising a titanium-glyoxal complex and a porous support material, wherein the porous support material comprises at least one of activated carbon, graphene, graphene oxide, silicon, or porous silicon.

Claim 2: The sorbent of claim 1, wherein the sorbent is configured for use in an apparatus for conducting dialysis.

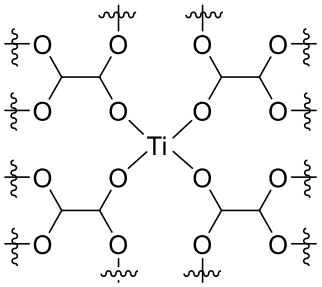
Claim 3: The sorbent of claim 1 or 2, wherein the titanium-glyoxal complex comprises titanium-crosslinked hydrated glyoxal moieties.

Claim 4: The sorbent of claim 1 or 2, wherein the titanium-glyoxal complex is formed by reacting hydrated glyoxal with titanium ions.

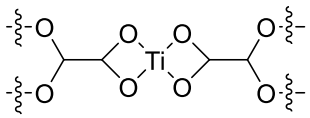
Claim 5: The sorbent of claim 1 or 2, wherein the titanium-glyoxal complex has a structure comprising a molecule of formula I, formula II, formula III, formula IV, or a combination thereof:



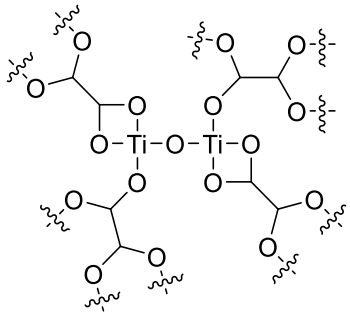
(I),



(II),



(III), or



(IV).

Claim 6: The sorbent of claim 1 or 2, wherein the titanium-glyoxal complex is associated with, adhered to, adsorbed on, coated on, and/or immobilized on the porous support material.

Claim 7: The sorbent of claim 1 or 2, wherein the titanium-glyoxal complex is present in pores of the porous support material.

Claim 8: The sorbent of claim 2, having a urea sorption capacity of greater than about 50 mg urea/g sorbent, such as greater than about 60 mg/g, greater than about 70 mg/g, greater than about 75 mg/g, greater than about 80 mg/g, greater than about 90 mg/g, about 50 mg/g to about 200 mg/g, about 50 mg/g to about 150 mg/g, about 50 mg/g to about 100 mg/g, about 60 mg/g to about 100 mg/g, about 70 mg/g to about 90 mg/g, about 75 mg/g to about 85 mg/g, and/or about 80 mg/g,

wherein the urea sorption capacity is calculated according to the following equation:

$$q=([BUN]_i - [BUN]_t) \times (60/28) \times V/100/S$$

wherein q is urea capacity in mg urea/g sorbent; $[BUN]_i$ is concentration of BUN in dialysate solution at time 0 in mg/dL; $[BUN]_t$ is concentration of BUN in dialysate solution at time t in mg/dL; V is volume of test solution in ml; and S is weight of sorbent in g.

Claim 9: The sorbent of claim 1 or 2, wherein the molar ratio of titanium to glyoxal is about 1:4.

Claim 10: A sorbent cartridge comprising the sorbent of claim 1 or 2.

Claim 11: The sorbent cartridge of claim 10, wherein the sorbent cartridge is free of an immobilized urease layer.

Claim 12: The sorbent cartridge of claim 10, wherein total content of active urease in a fluid flow compartment of the cartridge is less than about 5 wt. % based on a total immobilized weight of cartridge contents.

Claim 13: The sorbent cartridge of claim 10, wherein the sorbent cartridge is configured to hold dialysate fluid which communicates with the sorbent.

Claim 14: The sorbent cartridge of claim 10, further comprising a layer comprising titanium oxide, hydrous titanium dioxide, and/or titanium phosphate.

Claim 15: A method comprising passing a fluid comprising urea though the sorbent of claim 1 and/or through the sorbent cartridge of claim 10, thereby binding urea to the titanium-glyoxal complex.

Claim 16: An apparatus for conducting dialysis comprising the sorbent cartridge of claim 10, and a dialyzer in fluid communication with the sorbent cartridge, wherein spent dialysis fluid passes from the dialyzer to and through the sorbent cartridge.

Claim 17: The apparatus of claim 16, wherein the dialyzer is in fluid communication with the blood of a patient.

Claim 18: A dialysis system comprising the sorbent cartridge of claim 10 and a source of spent dialysis fluid, wherein the source of spent dialysis fluid is in fluid communication with the sorbent cartridge and the spent dialysis fluid passes to and through the sorbent cartridge.

Claim 19: A method of making a sorbent for binding urea, comprising:

(i) combining glyoxal, a titanium ion source, and a solvent to provide a mixture comprising a titanium-glyoxal complex;

(ii) adding activated carbon to the mixture to provide a treated activated carbon;

(iii) separating the solvent from the treated activated carbon;

(iv) washing the treated activated carbon to provide a washed treated activated carbon; and

(v) drying the washed treated activated carbon to provide a sorbent for binding urea.

Claim 20: The method of claim 19, wherein the titanium ion source is selected from the group consisting of titanium tetrachloride, titanium (II) chloride, titanium (III) chloride, titanium oxychloride, and combinations thereof.