Claims

1. A method of removing water from the atmosphere, comprising the steps of:

(a) providing a composite material to ambient atmospheric conditions for a period of time to adsorb water from the atmosphere, the composite material comprising:

a plurality of water-stable metal-organic frameworks, each having a plurality of porous cavities; and

a temperature-sensitive polymeric material in the form of polymer chains, wherein

the polymer chains of the temperature-sensitive polymeric material are formed at least partly within the porous cavities of the plurality of water-stable metal-organic frameworks;

the temperature-sensitive polymeric material has a lower critical solution temperature (LCST) of from 25 to 50°C; and

(b) heating the composite material to a temperature of from 5 to 20°C above the lower critical solution temperature of the temperature-sensitive polymeric material to regenerate the composite material.

2. The method according to Claim 1, wherein each polymer chain extends through one or more of the plurality of cavities in a single metal-organic framework.

3. The method according to Claim 1 or Claim 2, wherein a portion of the polymer chains extend from one or more cavities in a single metal-organic framework and into one or more cavities of at least one further metal-organic framework.

4. The method according to any one of the preceding claims, wherein at least part of one or more (e.g. two or three) polymer chains occupy the same cavity of a metal-organic framework.

5. The method according to any one of the preceding claims, wherein the water-stable metal-organic framework is formed from one or more of the group consisting of MOF-801, MOF-841, UiO-66, PIZOF-2, MIL-100(Fe), MIL-101(Al), MIL-125-NH_2, Co_2Cl_2(BTDD), Y-shp-MOF-5, and MIL-101(Cr).

6. The method according to any one of the preceding claims, wherein the water-stable metal-organic framework is MIL-101(Cr).

7. The method according to any one of the preceding claims, wherein the temperature-sensitive polymeric material is selected from one or more of the group consisting of polyethylene oxide (PEO), poly(ethylene oxide-co-propylene oxide) (poly(EO/PO) copolymers), PEO–PPO–PEO triblock surfactants, alkyl-PEO block surfactants, poly(vinyl methyl ether) (PVME), poly(oxyethylene vinyl ether) (POEVE), polymeric alcohols, hydroxypropyl acrylate, hydroxypropyl methylcellulose, hydroxypropyl cellulose, methylcellulose, poly(vinyl alcohol) and derivatives, polyamides, poly(N-vinyl pyrrolidone), poly(ethyl oxazoline), poly(N-vinylisobutylamide) (PNVIBA), poly(2-carboxyisopropylacrylamide) (PCIPAAm), poly(methacrylic acid), artificial polypeptides, triblock co-polypeptides that consist of short “leucine zipper” end blocks, elastin-like polypeptides (ELPs), and poly(N-isopropylacrylamide).

8. The method according to any one of Claims 1 to 6, wherein the temperature-sensitive polymeric material is selected from one or more of the group consisting of a poly(N-vinylamide) and a polyacrylic acid, or a derivative of a polyacrylic acid.

9. The method according to Claim 8, wherein the poly(N-vinylamide) is selected from one or more of the group consisting of poly(N-vinyl pyrrolidone), poly(N-vinylisobutylamide) (PNVIBA), and poly(2-carboxyisopropylacrylamide).

10. The method according to Claim 8, wherein the polyacrylic acid is selected from one or more of polyacrylic acid and poly(methacrylic acid).

11. The method according to Claim 8, wherein the polyacrylic acid derivative is a polyacrylamide.

12. The method according to Claim 11, wherein the polyacrylamide is selected from one or more of poly(N-isopropylacrylamide), and poly(N,N-diethylacrylamide).

13. The method according to any one of the preceding claims, wherein the temperature-sensitive polymeric material is poly(N-isopropylacrylamide).

14. The method according to any one of the preceding claims, wherein the water-stable metal-organic framework is MIL-101(Cr) and the temperature-sensitive polymeric material is poly(N-isopropylacrylamide).

15. The method according to any one of the preceding claims, wherein the temperature-sensitive polymeric material forms from 20 to 95 wt% of the total dry weight of the composite material, such as from 38 to 85 wt%.

16. The method according to any one of the preceding claims, wherein the composite material can adsorb a maximum of from 100 to 440 wt% of water relative to the dry weight of the composite material when exposed to saturated humid air conditions for a period of 24 hours.

17. The method according to any one of the preceding claims, wherein the heating in step (b) is from 7 to 15°C above the lower critical solution temperature of the temperature-sensitive polymeric material.

18. Use of a composite material as described in any one of Claims 1 to 16 for adsorption and release of water.

19. The use of Claim 18, wherein the adsorption of water is the adsorption of atmospheric water.

20. A composite material comprising:

a plurality of water-stable metal-organic frameworks, each having a plurality of porous cavities; and

a temperature-sensitive polymeric material in the form of polymer chains, wherein

the polymer chains of the temperature-sensitive polymeric material are formed at least partly within the porous cavities of the plurality of water-stable metal-organic frameworks;

the temperature-sensitive polymeric material has a lower critical solution temperature (LCST) of from 25 to 50°C; and

the composite material can adsorb a maximum of from 100 to 440 wt% of water relative to the dry weight of the composite material when exposed to saturated humid air conditions for a period of 24 hours.