
A bio-based nanofibre hydrogel filter for sustainable water purification

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Supplementary Information for

A bio-based nanofiber hydrogel filter for sustainable water purification

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S1. Supplementary Tables

The dirty river water was collected from a small river in Harbin city after the rain. The river water is very dirty and turbid. After using BNHF for filtration, the quality (different testing indicators) of the filtrated water meets the standards for drinking water quality (GB 5749-2006), confirming the filtration ability of BNHF for dirty river water.

Supplementary Table S1. The quality of water after filtrating from the dirty river water.

Test items	Test results	Standard limit	Unit
Total coliform	Not detected	Shall not be detected	MPN/100 mL
Total number of bacteria	9	100	CFU/mL
Chromaticity	< 5	15	degree
The stench and the smell	None	None	/
Visible object	None	None	/
pH	7.3	6.5~8.5	/
Total dissolved solids	183	1000	mg L ⁻¹
Total hardness	90	450	mg L ⁻¹
Consumed oxygen demand	0.75	3 (5)	mg L ⁻¹
Ammonia nitrogen	0.31	0.5	mg L ⁻¹

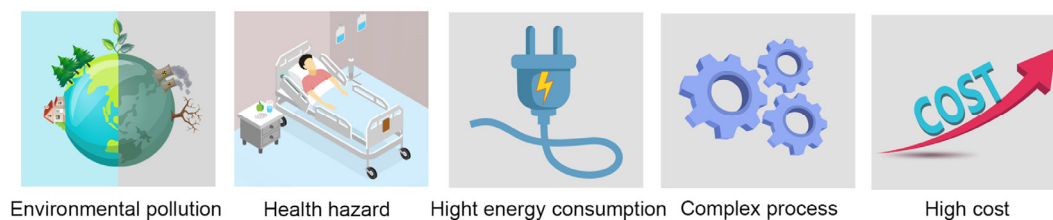
The cost of the BNHF is calculated from the total cost of its construction units. The prices for a syringe-driven filter, a 5 mL syringe, a piece of the commercial microporous membrane, and 10 mL of 0.5 wt% NFC aqueous dispersion (the cost of 10 mL, 0.5 wt% NFC aqueous dispersion is calculated from the cost of production of NFC from 60 g poplar wood powder) are around \$1.5786, \$0.0493, \$0.0333, and \$0.0366, respectively. Therefore, the total cost of a standard BNHF is about \$1.6978.

Supplementary Table S2. Details of the cost of a standard BNHF.

Construction units	Number/Items		Price
Syringe-driven filter	1		\$1.5786
5 mL syringe	1		\$0.0493
Commercial microporous membrane	1		\$0.0333
10 mL NFC aqueous dispersion (0.5 wt%)	Raw material	Poplar wood powder	\$0.0002
		Sodium chlorite	\$0.0130
	Chemicals	Acetic acid	\$0.0007
		Potassium hydroxide	\$0.0198
	Others	Filter paper	\$0.0012
		Electricity cost	\$0.0017

S2. Supplementary Figures

When water is polluted by SS, it can bring many hazards and negative impacts, including environmental pollution, endangering human health, requiring high energy consumption, complex processes, and high costs to purify water contaminated by SS.



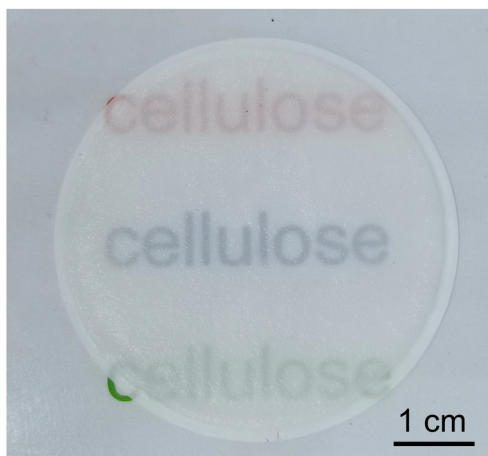
Supplementary Figure S1. Schematic illustration of the hazards of water pollution caused by SS.

The building units of the BNHF: a syringe-driven filter, a syringe, a support, and a bottle of NFC aqueous suspension (0.5 wt%).



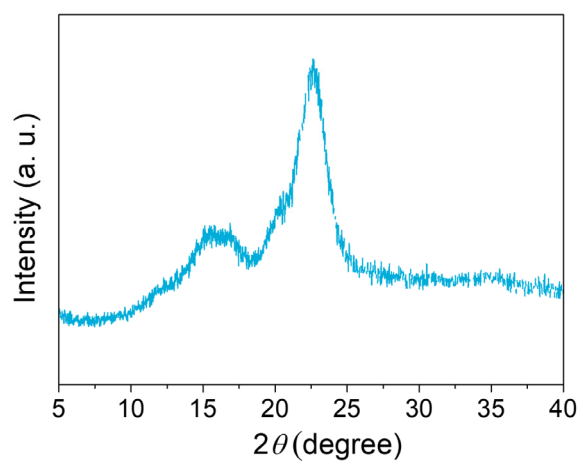
Supplementary Figure S2. Digital photographs of the BNHF construction units and the as-assembled BNHF.

In the syringe-driven filter, the hydrogel film is densely deposited on the microporous membrane. Due to the slender size of cellulose nanofibers and the densely packed NFC, the hydrogel film/microporous membrane composite structure shows some transparency.



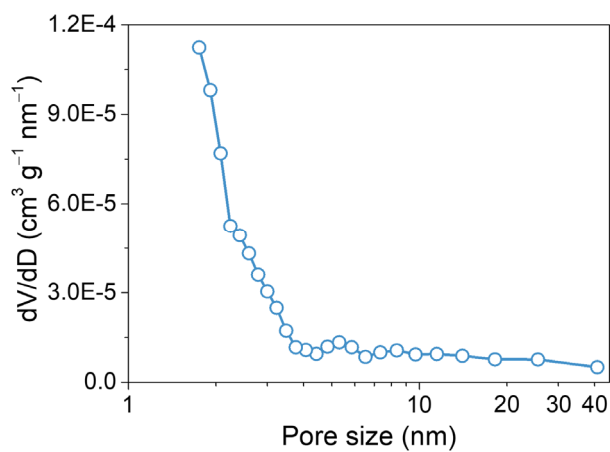
Supplementary Figure S3. Digital photograph of a HF-5-10 deposited on a microporous membrane.

The XRD pattern of NFC confirms that NFC contains highly crystalline cellulose nanofibers.



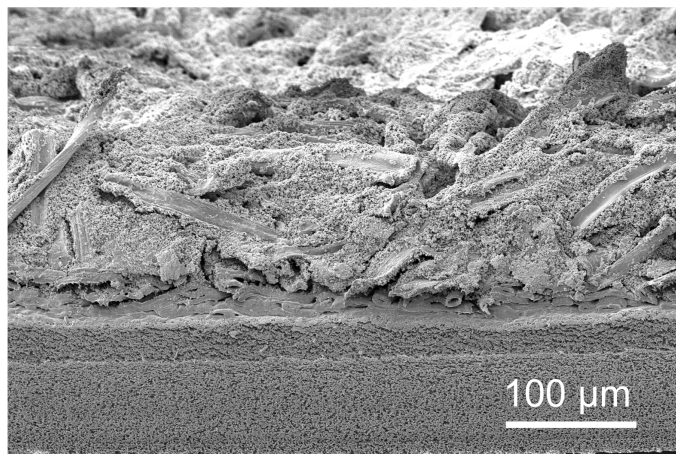
Supplementary Figure S4. XRD pattern of the wood NFC.

To reflect the pore structure of the hydrogel film, the pore size distribution of the aerogel film produced by freeze-drying the HF-5-10 was tested. The pore size of the aerogel film is 1.7~40.8 nm.



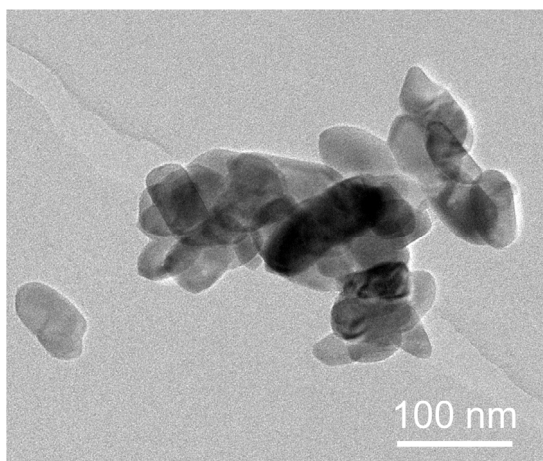
Supplementary Figure S5. Pore size of the aerogel film produced by freeze-drying the HF-5-10.

The aqueous dispersion of 30~50 nm TiO₂ nanoparticles was filtered by BNHF containing HF-5-10. The SEM image of the dried sample after filtration showed that a large number of TiO₂ nanoparticles were intercepted by the HF-5-10, demonstrating the ability of BNHF to remove ultrafine TiO₂ nanoparticles for water purification.



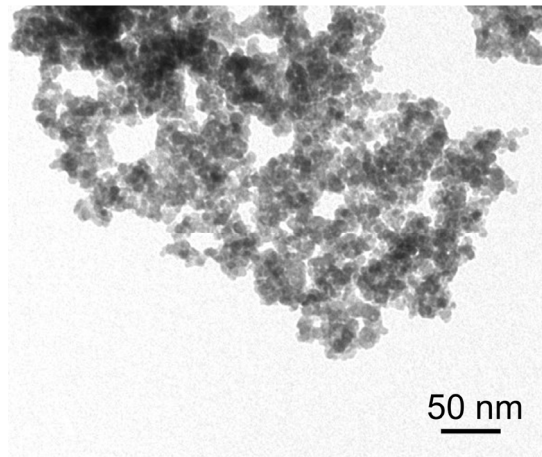
Supplementary Figure S6. SEM image of the composite structure of hydrogel film/microporous membrane after filtering TiO₂ nanoparticles.

Rod-shaped TiO_2 nanoparticle water dispersion was used for filtration to evaluate the interception performance of the BNHFs. TEM image exhibits that the width of the TiO_2 nanoparticles is 30~50 nm.



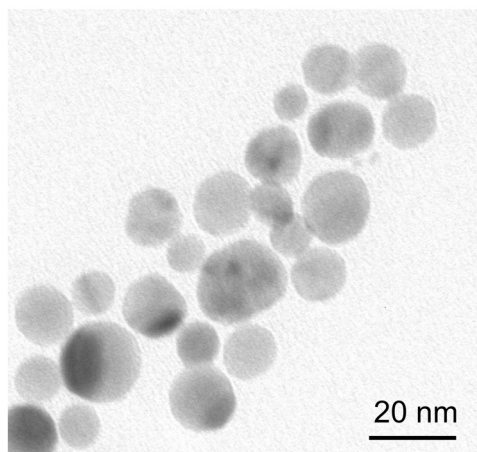
Supplementary Figure S7. TEM image of 30~50 nm TiO_2 nanoparticles.

ATO nanoparticle water dispersion was used for filtration to evaluate the interception performance of the BNHFs. TEM image exhibits that the size of the ATO nanoparticles is 20~80 nm.



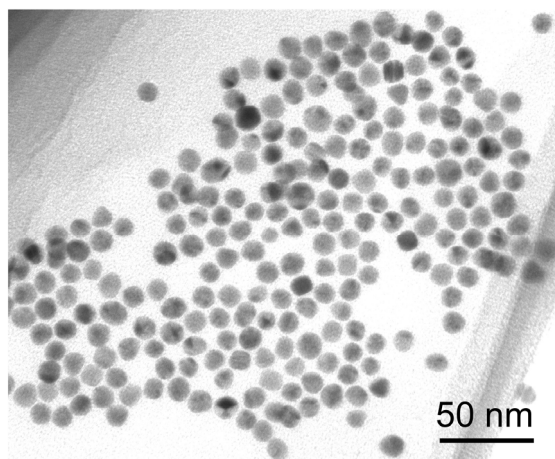
Supplementary Figure S8. TEM image of 20~80 nm ATO nanoparticles.

Ag nanoparticle water dispersion was used for filtration to evaluate the interception performance of the BNHFs. TEM image exhibits that the size of the Ag nanoparticles is ~ 15 nm.



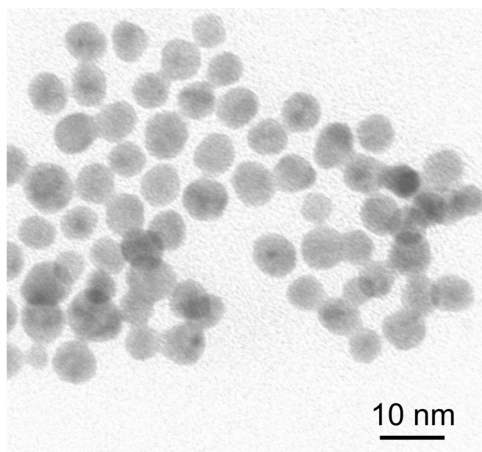
Supplementary Figure S9. TEM image of 15 nm Ag nanoparticles.

Au nanoparticle water dispersion was used for filtration to evaluate the interception performance of the BNHFs. TEM image exhibits that the size of the Au nanoparticles is ~ 10 nm.



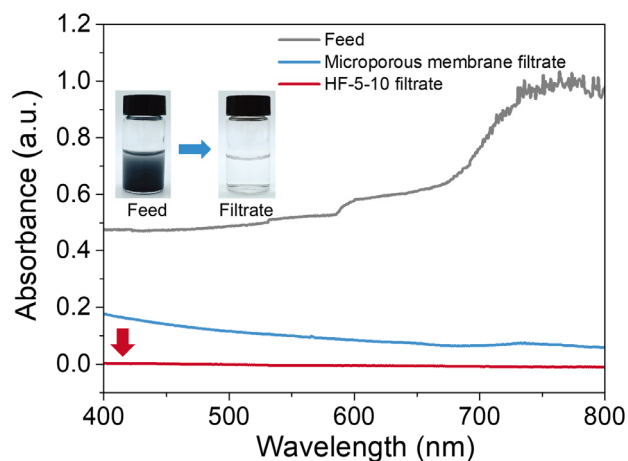
Supplementary Figure S10. TEM image of 10 nm Au nanoparticles.

Au nanoparticle water dispersion was used for filtration to evaluate the interception performance of the BNHFs. TEM image exhibits that the size of the Au nanoparticles is ~ 5 nm.



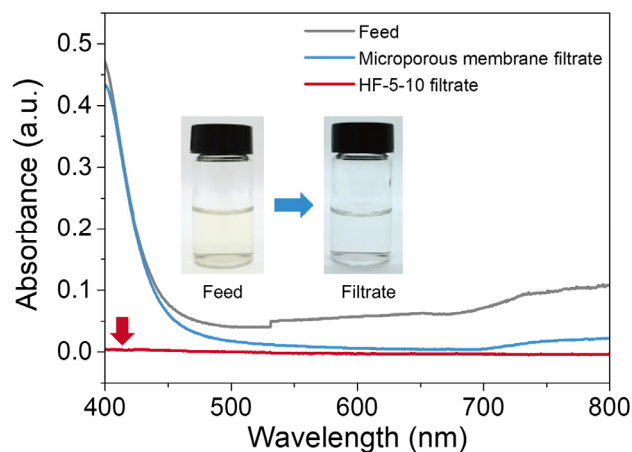
Supplementary Figure S11. TEM image of 5 nm Au nanoparticles.

20~80 nm ATO nanoparticle water dispersion was filtrated with a microporous membrane and a HF-5-10 deposited on a microporous membrane, respectively. After filtration, ATO nanoparticles still existed in the filtrate of the microporous membrane, while the HF-5-10 almost completely blocked the SS, and pure water was obtained.



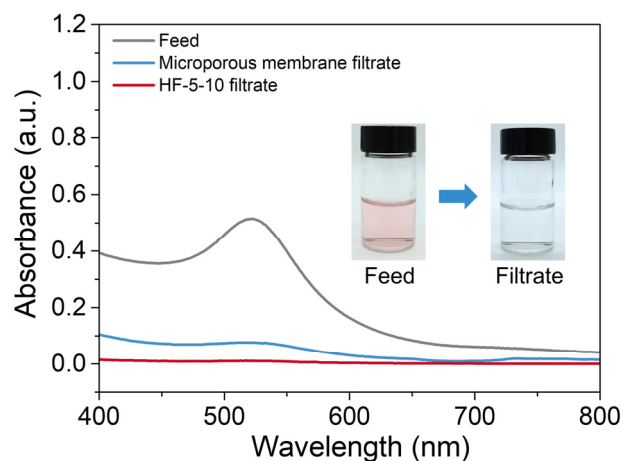
Supplementary Figure S12. UV-vis spectra of the feed and filtrate of 20~80 nm ATO nanoparticle water dispersion filtered through a microporous membrane or a HF-5-10 by manual pressure. The inset shows digital photographs of the feed and HF-5-10 filtrate.

15 nm Ag nanoparticle water dispersion was filtrated with a microporous membrane and a HF-5-10 deposited on a microporous membrane, respectively. After filtration, Ag nanoparticles still existed in the filtrate of the microporous membrane, while the HF-5-10 almost completely blocked the SS, and pure water was obtained.



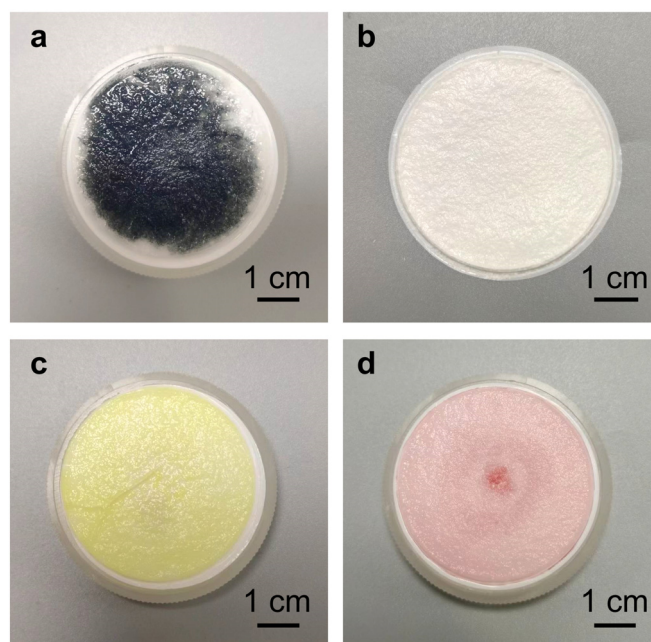
Supplementary Figure S13. UV-vis spectra of the feed and filtrate of 15 nm Ag nanoparticle water dispersion filtered through a microporous membrane or a HF-5-10 by manual pressure. The inset shows digital photographs of the feed and HF-5-10 filtrate.

10 nm Au nanoparticle water dispersion was filtrated with a microporous membrane and a HF-5-10 deposited on a microporous membrane, respectively. After filtration, Au nanoparticles still existed in the filtrate of the microporous membrane, while the HF-5-10 almost completely blocked the SS, and pure water was obtained.



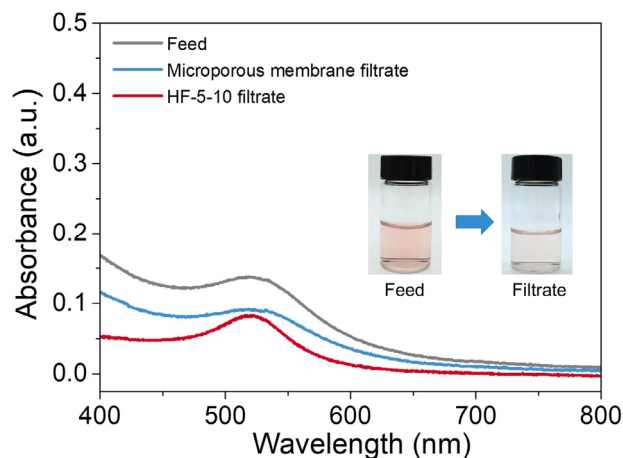
Supplementary Figure S14. UV-vis spectra of the feed and filtrate of 10 nm Au nanoparticle water dispersion filtered through a microporous membrane or a HF-5-10 by manual pressure. The inset shows digital photographs of the feed and HF-5-10 filtrate.

BNHFs containing HF-5-10 were used to filtrate water dispersions of different types and sizes of nanoparticles. After filtration, the 20~80 nm ATO, 30~50 nm TiO₂, 15 nm Ag, and 10 nm Au nanoparticles were rejected.



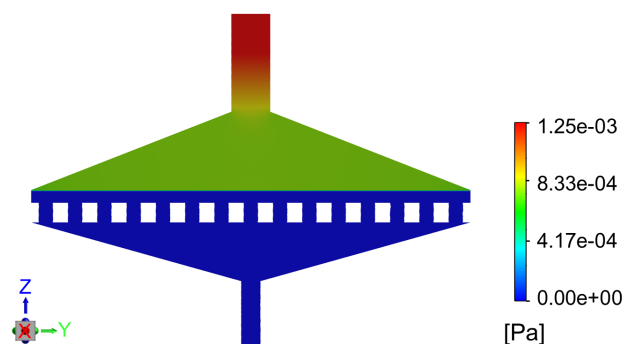
Supplementary Figure S15. Digital photographs of the HF-5-10 after filtration of (a) 20~80 nm ATO, (b) 30~50 nm TiO₂, (c) 15 nm Ag, and (d) 10 nm Au nanoparticle water dispersion.

5 nm Au nanoparticle water dispersion was filtrated with a microporous membrane and a HF-5-10 deposited on a microporous membrane, respectively. After filtration, Au nanoparticles still existed in the filtrate of the microporous membrane and HF-5-10, indicating that the filter material can not completely remove 5 nm Au nanoparticles from water.



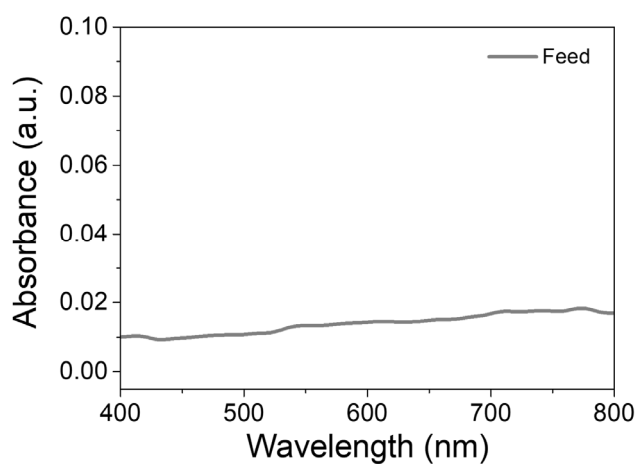
Supplementary Figure S16. UV-vis spectra of the feed and filtrate of 5 nm Au nanoparticle water dispersion filtered through a microporous membrane or a HF-5-10 by manual pressure. The inset shows digital photographs of the feed and HF-5-10 filtrate.

CFD simulation was used to demonstrate the pressure distribution for the filtration of 10~20 nm TiO₂ nanoparticle water dispersion using BNHF containing HF-5-10. The pressure generated by hand injection is mainly applied to the upper area of HF-5-10.



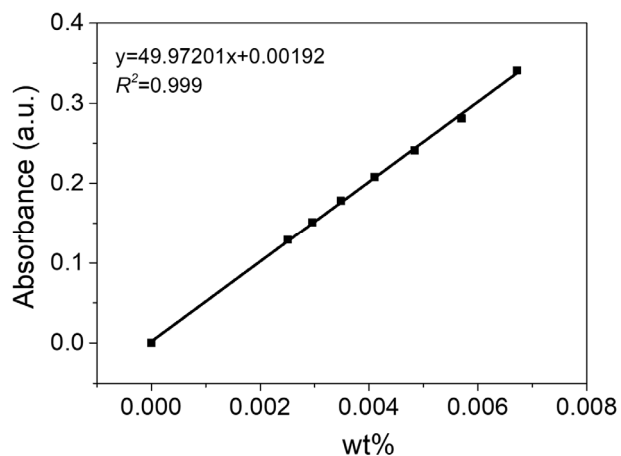
Supplementary Figure S17. CFD simulation of the pressure distribution of the filtration of 10~20 nm TiO₂ nanoparticle water dispersion by manual pressure using BNHF containing HF-5-10.

30~50 nm TiO₂ nanoparticle water dispersion (0.0002 wt%) was used for filtration via manual pressure using a BNHF containing HF-5-10. UV-vis spectrum shows the presence of particulate matter in the nanoparticle water dispersion, which is obviously not clean water.



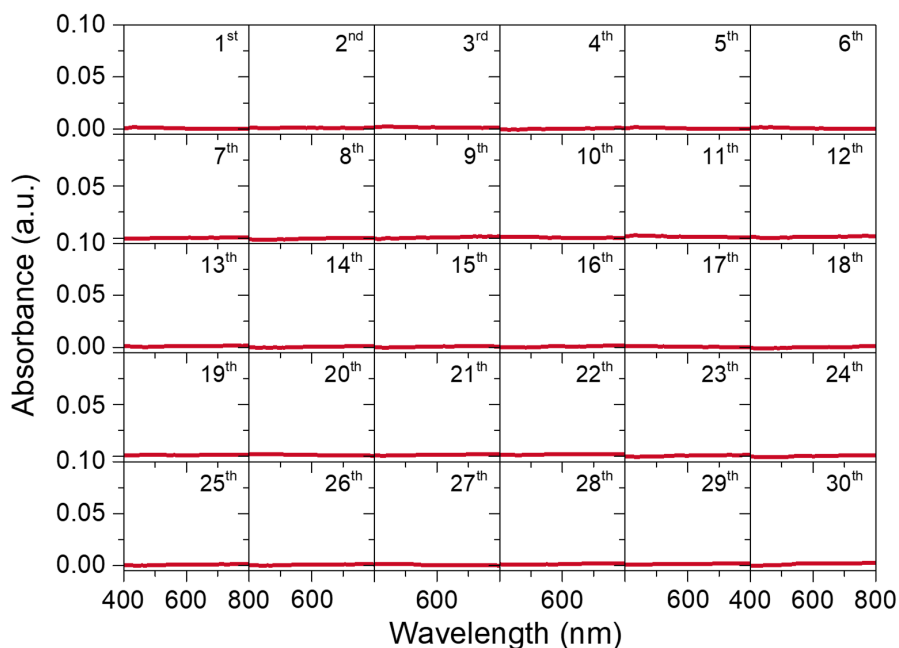
Supplementary Figure S18. UV-vis spectrum of the 30~50 nm TiO₂ nanoparticle water dispersion with nanoparticle concentration of 0.0002%.

UV-vis tests were conducted on 30~50 nm TiO₂ nanoparticle water dispersions with different concentrations. By measuring the absorbance at a wavelength of 736 nm, the standard curve of TiO₂ nanoparticle water dispersions was obtained, with an R-squared of 0.999. This standard curve was used to detect the concentration of 30~50 nm TiO₂ nanoparticles in the filtrate.



Supplementary Figure S19. UV-vis standard curve of 30~50 nm TiO₂ nanoparticle water dispersion at a wavelength of 736 nm.

A BNHF containing HF-5-10 was used to filtrate 30~50 nm TiO₂ nanoparticle water dispersion (0.0002 wt%) 30 times. First, 10 mL TiO₂ nanoparticle water dispersion was filtrated via manual pressure. Then, 10 mL TiO₂ nanoparticle water dispersion was filtrated with the BNHF that has just been used for filtration of 10 mL TiO₂ nanoparticle water dispersion. The process was repeated 30 times. The UV-vis spectra of the filtrates indicate that TiO₂ nanoparticles were almost completely rejected during each filtration. Every filtration process yielded pure water.



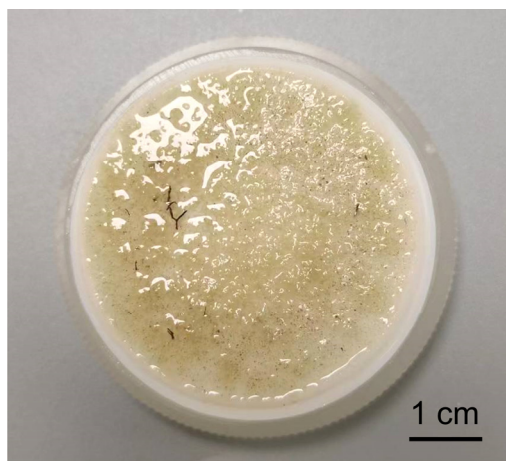
Supplementary Figure S20. UV-vis spectra of the filtrates of 30 times filtration of 10 mL of 30~50 nm TiO₂ nanoparticle water dispersion through a HF-5-10.

The HF-5-10 was used for filtration of 30~50 nm TiO₂ nanoparticle water dispersion (0.0002 wt%) 30 times (10 mL each time). After filtration, HF-5-10 is not contaminated by microorganisms. From its surface appearance, there is no mold.



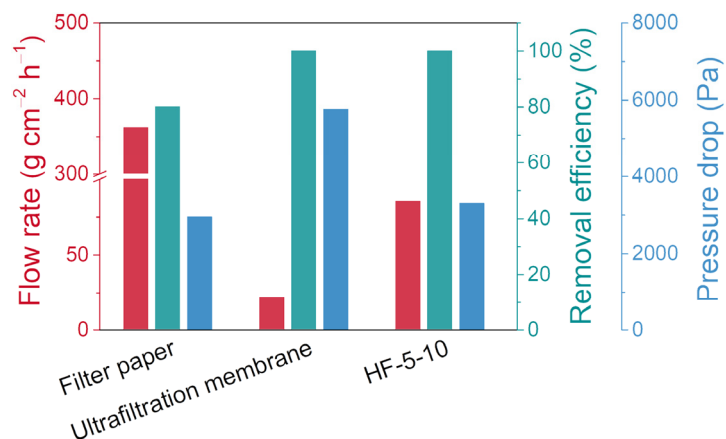
Supplementary Figure S21. Digital photograph of the HF-5-10 after filtration of 30~50 nm TiO₂ nanoparticle water dispersion (0.0002 wt%) 30 times.

A BNHF containing HF-5-10 was used to filtrate soil-containing water. After filtration, the soil particles were rejected. The digital photograph demonstrates that many soil particles are intercepted by the upper surface of the HF-5-10.



Supplementary Figure S22. Digital photograph of the HF-5-10 after filtration of soil-containing water.

10 mL soil-contaminated water (0.5 wt%) was filtered by commercial filter paper, polycarbonate ultrafiltration membrane and HF-5-10, respectively. Considering flow rate, pressure drop and soil removal efficiency, the hydrogel film is the best choice for dirty water purification.



Supplementary Figure S23. Liquid flow rate, pressure drop and soil removal efficiency of filtrating soil-contaminated water (0.5 wt%) via different materials.

The dirty river water was collected from a small river (Majiagou River) in the city of Harbin. The two sides of the river are sloping earth slopes. After the rain, a lot of soil and debris enter the river, causing it to be very turbid and have a foul odor. The dirty river water was collected directly from the riverbank using a water bottle.



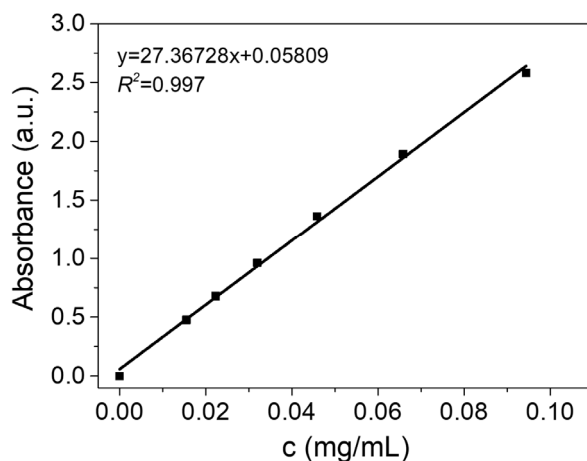
Supplementary Figure S24. Digital photograph showing the collection of dirty river water in a river after rain.

The water obtained from melting snow collected outdoors is dirty. A BNHF containing HF-5-10 was used to filtrate the melting snow water. After filtration, the dirty particles were rejected. The digital photograph demonstrates that many dirty particles are intercepted by the upper surface of the HF-5-10.



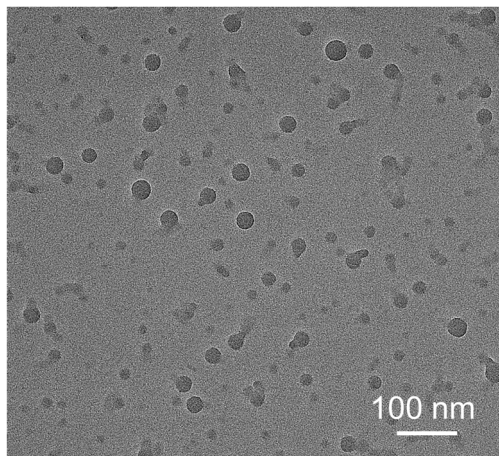
Supplementary Figure S25. Digital photograph of the HF-5-10 after filtration of melted snow water.

UV–vis tests were conducted on 30 nm polystyrene nanoparticle water dispersions with different concentrations. By measuring the absorbance at a wavelength of 219 nm, the standard curve of 30 nm polystyrene nanoparticle water dispersions was obtained, with an R-squared of 0.997. This standard curve was used to detect the concentration of 30 nm polystyrene nanoparticle in the filtrate.



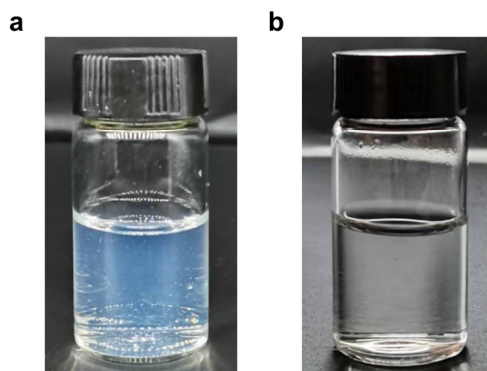
Supplementary Figure S26. UV–vis standard curve of 30 nm polystyrene nanoparticle water dispersion at a wavelength of 219 nm.

~30 nm polystyrene nanoplastic water dispersion was used for filtration to evaluate the interception performance of the BNHF. TEM image shows that the size of most of the polystyrene nanoplastics is around 30 nm. However, there are also a small number of nanoplastics with a size of approximately 10 nm or even less than 10 nm in the sample, which will to some extent increase the difficulty of purifying the nanoplastic-containing water.



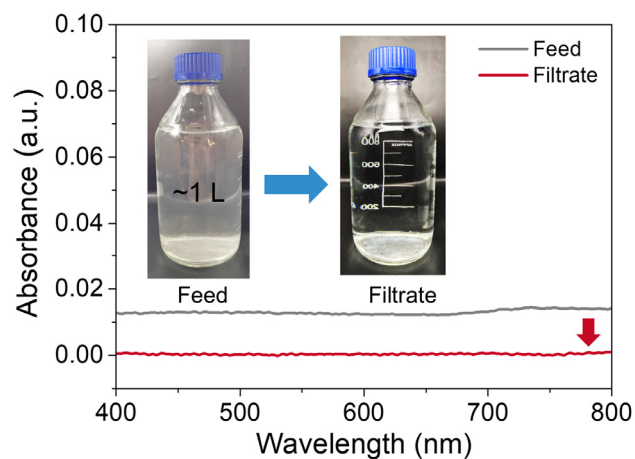
Supplementary Figure S27. TEM image of 30 nm polystyrene nanoplastics.

0.5 mg mL⁻¹ polystyrene nanoplastic (most nanoplastics have a diameter of ~30 nm, while some plastics have smaller sizes, even less than 10 nm) water dispersion is turbid. After two times filtration using a BNHF containing HF-10-15, the nanoplastics were rejected by the HF-10-15, and clean water was obtained.



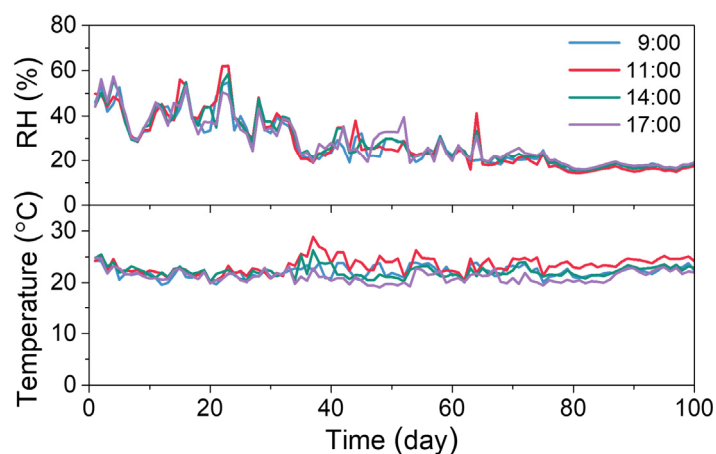
Supplementary Figure S28. Digital photographs of 30 nm polystyrene nanoplastic water dispersion (a) before and (b) after filtration by a BNHF containing HF-10-15.

30~50 nm TiO₂ nanoparticle water dispersion (0.0002 wt%) was filtrated with a HF-5-1000 deposited on a microporous membrane via manual pressure. The dispersion is turbid. After filtration, TiO₂ nanoparticles were almost completely blocked by the HF-5-1000, and clean water was obtained.



Supplementary Figure S29. UV-vis spectra of the feed and filtrate of 30~50 nm TiO₂ nanoparticle water dispersion filtered through a HF-5-1000. The inset shows digital photographs of the feed and HF-5-1000 filtrate.

The HF-5-10, commercial nanoporous nylon membrane, and commercial nanoporous polycarbonate membrane were placed on grassy soil 100 days for evaluating the biodegradability. The temperature and relative humidity (RH) of the environment were recorded at 9:00, 11:00, 14:00, and 17:00 every day. The environmental temperature and RH are constantly changing at different times of each day and within different days.



Supplementary Figure S30. Ambient temperature and RH during biodegradation experiments of HF-5-10, commercial nanoporous nylon membrane, and commercial nanoporous polycarbonate membrane.

S3. Supplementary Videos

Video S1. The appearance of a BNHF shows that it is a very convenient filter. Related to Fig. 2a.

Video S2. X-ray micro-CT investigation revealing the three-dimensional structure of HF-5-10 on a microporous membrane. Related to Fig. 2k.