四川大学 新能源与低碳技术研究院
INSTITUTE OF NEW ENERGY AND LOW-CARBON TECHNOLOGY

新能源与膜技术研究中心

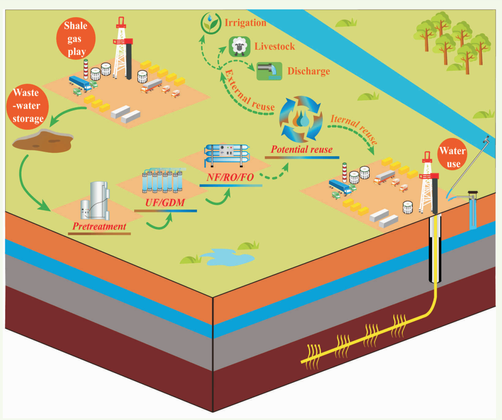
刘百仓教授课题组在页岩气返排液可持续回用方面的研究成果

研究背景

- 页岩气储量丰富，全球迎来“天然气黄金时代”，中国可开采量居世界第一，其中四川地区尤为丰富
- 开采需水量巨大，每口井水力压裂需水30000m³以上
- 废水量多，单井返排液和采出水可达25,000m³
- 水质成分复杂，盐度太高，硬度大，有机物种类多，处理难度极大
- 针对中国地区页岩气废水处理工艺匮乏

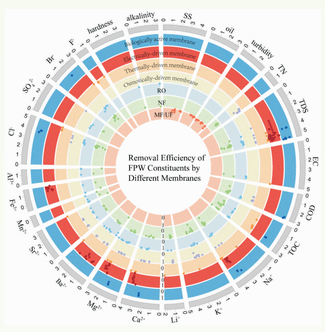
研究重点

基于膜技术的页岩气废水处理研究



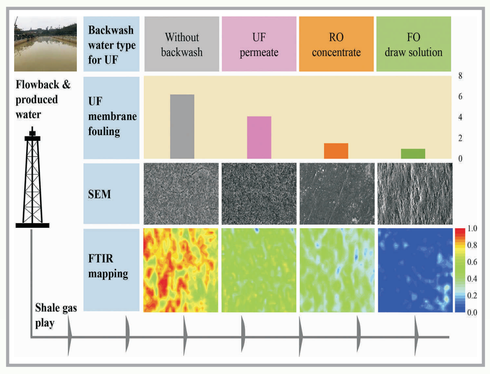
代表性研究成果

- 综述：膜技术在页岩气和油气田废水处理及再利用领域的潜力
  （发表于Desalination）

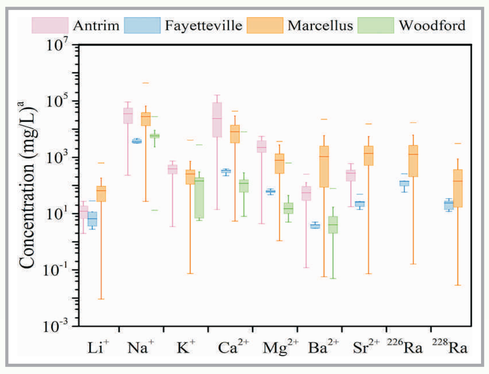


Metric	NF	RO	FO	MD	ED	MCDC
High-salinity feeds						
Salt rejection						
Low fouling tendency					/	/
Water recovery						
Energy efficiency						
Low pretreatment						
Low posttreatment						
Low lifetime costs						
Readiness level						

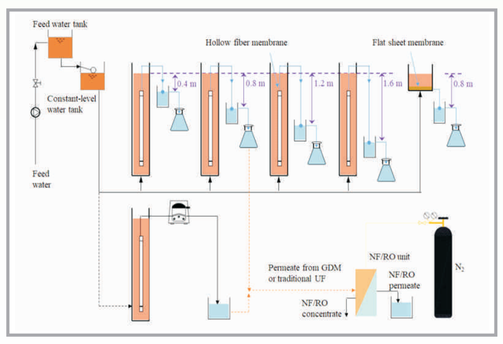
- 探究在页岩气废水处理中反冲洗液对超滤膜污染的影响机理
  （发表于Environment International）



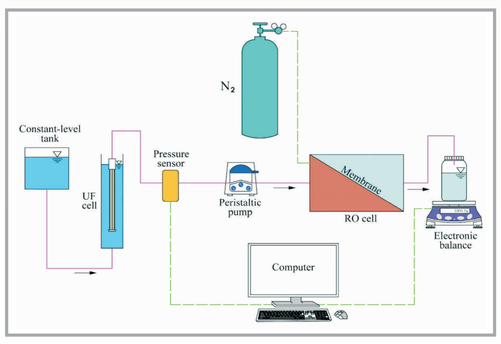
- 非常规页岩气和石油开采过程中水力压裂废水的资源化利用
  （发表于Environ. Sci. Technol.）



代表性研究工艺

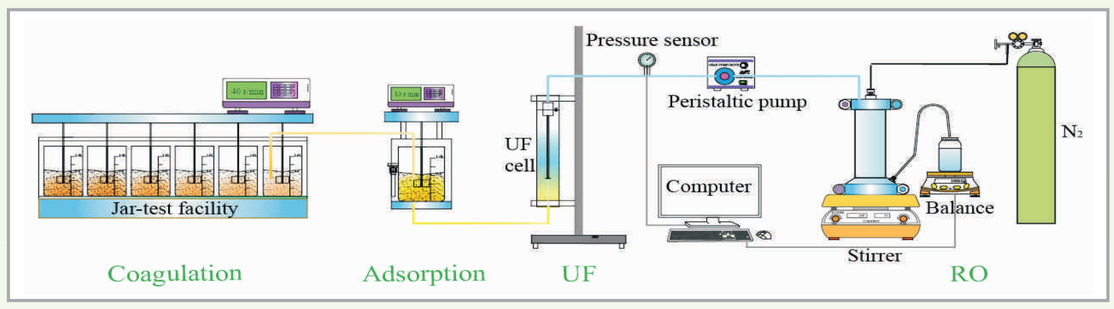


重力驱动超滤膜技术

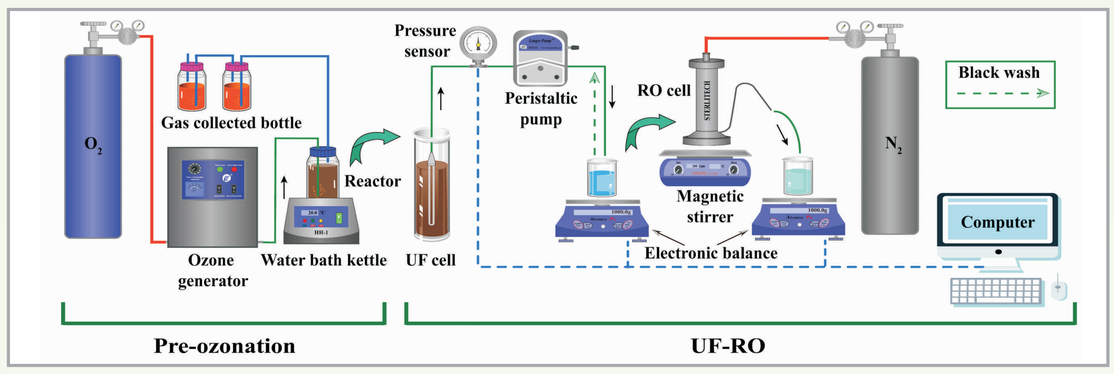


超滤-反渗透联用技术

混凝-超滤-纳滤联用技术



混凝-吸附-超滤-反渗透联用技术



臭氧-超滤-反渗透联用技术

研究成果

在页岩气废水处理领域代表性SCI论文10篇（国际领先）

1. P. Tang, B. Liu*, Y. Zhang*, H. Chang, P. Zhou, M. Feng, V.K. Sharma, Sustainable reuse of shale gas wastewater by pre-ozonation with ultrafiltration-reverse osmosis, Chem. Eng. J., 2020, 123743.
2. J. Li, H. Chang, P. Tang, W. Shang, Q. He, B. Liu*, Effects of membrane property and hydrostatic pressure on the performance of gravity-driven membrane for shale gas flowback and produced water treatment, J. Water Process Eng., 2020, 33, 101117.
3. H. Chang, B. Liu*, J.C. Crittenden, R.D. Vidic, Resource Recovery and Reuse for Hydraulic Fracturing Wastewater in Unconventional Shale Gas and Oil Extraction, Environ. Sci. Technol., 2019, 53, 13547-13548.
4. H. Chang, T. Li, B. Liu*, R.D. Vidic, M. Elimelech, J.C. Crittenden, Potential and implemented membrane-based technologies for the treatment and reuse of flowback and produced water from shale gas and oil plays: A review, Desalination 2019, 455, 34-57.
5. W. Shang, A. Tiraferri, Q. He, N. Li, H. Chang, C. Liu, B. Liu*, Reuse of shale gas flowback and produced water: Effects of coagulation and adsorption on ultrafiltration, reverse osmosis combined process, Sci. Total Environ. 2019, 689, 47-56.
6. Chang, H.; Liu, B.*; Wang, H.; Zhang, S.-Y.; Chen, S.; Tiraferri, A.; Tang, Y.-Q., Evaluating the performance of gravity-driven membrane filtration as desalination pretreatment of shale gas flowback and produced water. J. Membrane Sci. 2019, 587, 117187.
7. H. Chang, B. Liu*, B. Yang, X. Yang, C. Guo, Q. He, S. Liang, S. Chen, P. Yang, An integrated coagulation-ultrafiltration-nanofiltration process for internal reuse of shale gas flowback and produced water, Sep. Purif. Technol. 2019, 211, 310-321.
8. H. Chang, T. Li, B*. Liu, C. Chen, Q. He, J.C. Crittenden, Smart ultrafiltration membrane fouling control as desalination pretreatment of shale gas fracturing wastewater: The effects of backwash water, Environ. Int. 2019, 130, 104869.
9. C. Guo, H. Chang, B. Liu*, Q. He, B. Xiong, M. Kumar, A.L. Zydney, A combined ultrafiltration–reverse osmosis process for external reuse of Weiyuan shale gas flowback and produced water, Environ. Sci. Water Res. Technol. 2018, 18, (3), 808-818.
10. H. Chang, T. Liu, Q. He, D. Li, J. Crittenden, B. Liu*, Removal of calcium and magnesium ions from shale gas flowback water by chemically activated zeolite, Water Sci. Technol. 2017, 76, (3), 575-583.

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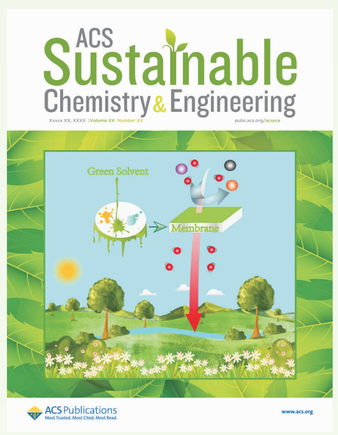
刘百仓教授课题组在高通量抗污染膜方面的研究成果

研究背景

- 使用原子转移自由基聚合法(ATRP)法合成了两亲性接枝物PVDF-g-PEGMA与PVC-g-PEGMA，与PVDF/PVC共混制备了高性能的超滤共混膜。
- 制备有机聚合膜时需要使用大量有机溶剂，而传统的有机溶剂会危害环境与人体健康，不符合可持续的绿色化学理念。

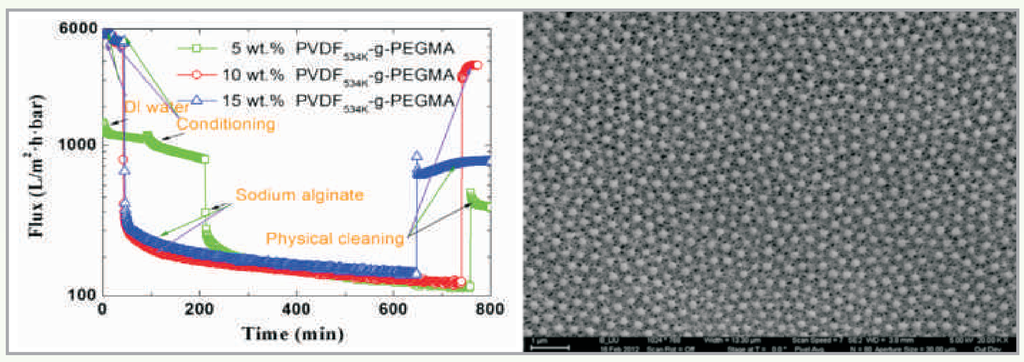
研究重点

基于绿色化学理念的高性能有机膜制备

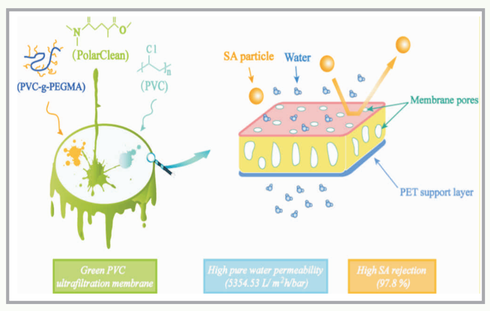


代表性研究成果

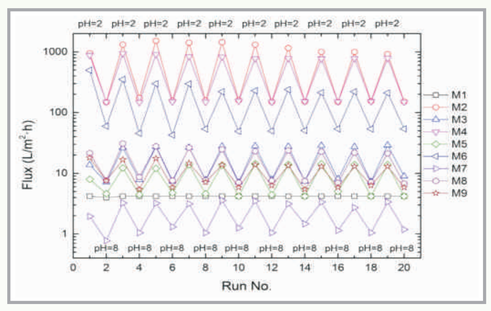
- 使用PVDF与其衍生共聚物PVDF-g-PEGMA制备的高性能超滤膜（发表于Journal of Membrane Science）



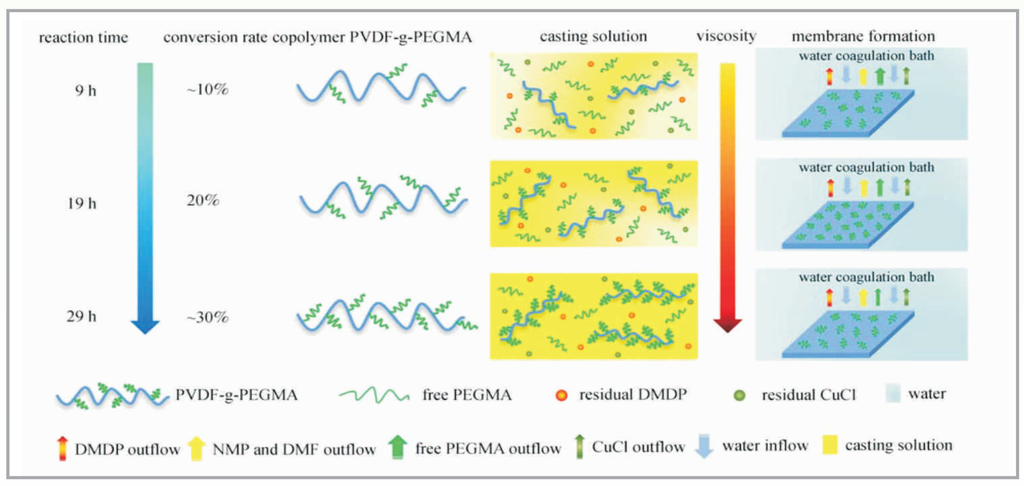
- 探究使用绿色溶剂Polar Clean制备PVC共混超滤膜（发表于ACS Sustainable Chemistry& Engineering）

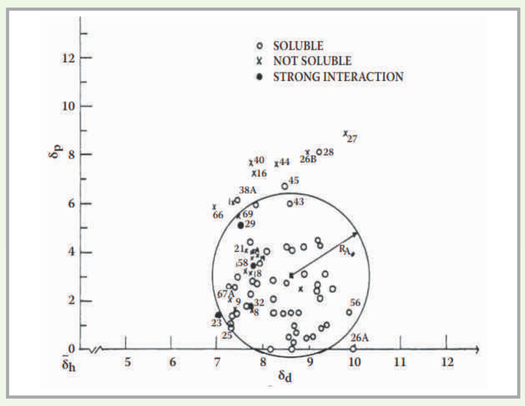


- 添加剂与溶剂对膜性质和性能的影响: PVDF/PVDF-g-PMAA PH响应膜（发表于Journal of Membrane Science）

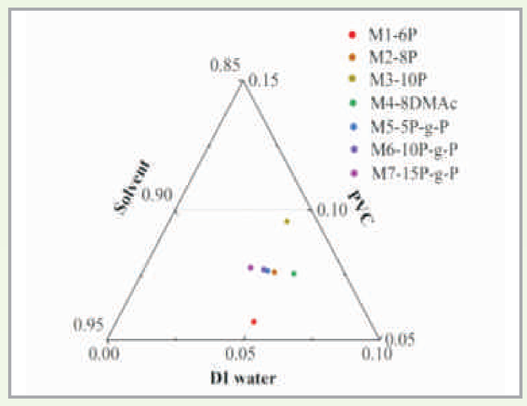


实验方法与理论





原子转移自由基聚合法
合成两亲性共聚物（ATRP）



运用Hansen溶解度参数理论
进行溶剂的选择、理论配比计算

研究成果

在膜制备领域10篇代表性SCI论文 (近3年)

1. **B.Liu***, S.Wang, P.Zhao, H.Liang, W.Zhang, J.C.Crittenden, High-performance polyamide thin-film composite nanofiltration membrane: Role of thermal treatment. Applied Surface Science, 2018, 435, 415-423..
2. S.Wang, T.Li, C.Chen, S.Chen, **B.Liu***, J.C.Crittenden, Non-woven PET fabric reinforced and enhanced the performance of ultrafiltration membranes composed of PVDF blended with PVDF-g-PEGMA for industrial applications, Applied Surface Science 2018, 435, 1072-1079.
3. S.Wang, T.Li, C.Chen, **B.Liu***, J.C.Crittenden, PVDF ultrafiltration membranes of controlled performance via blending PVDF-g-PEGMA copolymer synthesized under different reaction times, Frontiers of Environmental Science & Engineering, 2018, 12, (2), 3.
4. H.Wu, T.Li, **B.Liu***, C.Chen, S.Wang, J.C.Crittenden, Blended PVC/PVC-g-PEGMA ultrafiltration membranes with enhanced performance and antifouling properties. Applied Surface Science, 2018, 455, 987-996..
5. W.Xie, L.Tong, C.Chen, H.Wu, S.Liang, H.Chang, **B.Liu***, E.Drioli, Q.Wang, J.C.Crittenden. Using the Green Solvent Dimethyl Sulfoxide to Replace Traditional Solvents Partly and Fabricating PVC/PVC-g-PEGMA Blended Ultrafiltration Membranes with High Permeability and Rejection, Industrial & Engineering Chemistry Research, 2019, 58, 6413-6423.
6. Q.Wu, A.Tiraferri, H.Wu, W.Xie, **B.Liu***. Improving the Performance of PVDF/PVDF-g-PEGMA Ultrafiltration Membranes by Partial Solvent Substitution with Green Solvent Dimethyl Sulfoxide during Fabrication, ACS Omega, 2019, 4, 19799-19807.
7. Q.Wu, W.Xie, H.Wu, L.Wang, S.Liang, H.Chang, **B.Liu***. Effect of Volatile Solvent and Evaporation Time on Formation and Performance of Pvc/Pvc-G-Pegma Blended Membranes. RSC Advances, 2019, 9, 34486.
8. W.Xie, A.Tiraferri, **B.Liu***, P.Tang, F.Wang, S.Chen, A.Figoli, L.Chu. First Exploration on a Poly(Vinyl Chloride) Ultrafiltration Membrane Prepared by Using the Sustainable Green Solvent Polarclean. ACS Sustainable Chemistry & Engineering, 2020, 8, 91-101.
9. M.He, Z.Liu, T.Li, C.Chen, **B.Liu***, J.C.Crittenden. Effect of Adding a Smart Potassium Ion-Responsive Copolymer into Polysulfone Support Membrane on the Performance of Thin-Film Composite Nanofiltration Membrane. Frontiers of Chemical Science and Engineering, 2019, 13 (2), 400-414..
10. M.He, T.Li, M.Hu, C.Chen, **B.Liu***, J.C.Crittenden, L.Chu, H.Ng. Performance Improvement for Thin-Film Composite Nanofiltration Membranes Prepared on Psf/Psf-G-Peg Blended Substrates. Separation and Purification Technology, 2020, 230, 115855..