PROJECT SUMMARY
项目摘要

Saltworks Technologies Inc. (Saltworks) completed an off-site Flex EDR Selective pilot test to treat flue gas desulfurization (FGD) wastewater from a coal fired power plant in China. The objective was to reduce chlorides such that the FGD wastewater could be internally recycled and final treatment costs reduced notably. FGD wastewater is generated and released primarily due to chloride content that inhibits sulfur dioxide absorption in the stack and can cause corrosion problems. If chlorides can be removed, the FGD wastewater can be recycled.

Saltworks Technologies Inc.（Saltworks）成功应用Flex EDR Selective单价选择性电渗析处理中国某燃煤电厂的烟气脱硫（FGD）废水，完成了场外测试。测试目标是降低废水氯离子含量，实现脱硫废水内部回用，显著降低废水最终处理成本。脱硫废水的产生和排放主要是由于废水中高含量氯离子抑制二氧化硫吸收并导致设备腐蚀。如果可以去除其氯离子，脱硫废水可以回用。

The results showed that Saltworks Flex EDR Selective achieved:

- Reliable treatment built from the second most common membrane desalination technology - electrodialysis reverse (EDR) – with modernized membranes and process controls.
- 90% recovery on a highly scaling calcium sulfate FGD wastewater without the need for expensive soda ash softening. The system produced a predominantly calcium chloride brine with 127,000 mg/L total dissolved solids (TDS) concentration. The brine could be directly solidified with fly ash and other solidification agents for zero liquid discharge, eliminating the need for a crystallizer.
- Removed 78% of the chlorides with ease: treated water from ~6,900 mg/L chlorides to less than 1,500 mg/L, such that it could be recycled back to the FGD system.

测试结果显示Saltworks 的Flex EDR Selective成功：

- 采用第二最常见的膜脱盐技术 - 倒极电渗析（EDR），并结合现代化膜技术和处理工艺控制可靠处理了脱硫废水。
- 处理高度结垢的饱和硫酸钙的脱硫废水，实现90％回收率，无需昂贵的纯碱软化。该系统主要产生氯化钙浓水，其总溶解固体浓度（TDS）为127,000 mg/L，可以用飞灰和其他固化剂直接固化用于零排放，无需结晶器。
- 轻松去除78％的氯离子：产水从约6,900 mg/L氯离子降低至低于1,500 mg/L，实现循环回用。

The China coal fired power plant is seeking a solution for their FGD wastewater to meet forthcoming environmental regulations. Its FGD wastewater is currently treated by a “triple box” process, which adjusts pH and uses chemicals to remove organics, fluorides, and heavy metals. However, salinity and chlorides remain, which may be prohibited in the near future.

中国燃煤电厂正在寻求脱硫废水的解决方案，以满足即将出台的环境法规。该电厂的脱硫废水目前采用"三联箱"工艺处理。三联箱工艺通过调节pH值并使用化学品去除废水中的有机物、氟化物和重金属，但无法去除盐分和氯离子。在不久的将来，三联箱处理的废水可能会被禁止排放。

Saltworks Flex EDR Selective system selectively removes chlorides from FGD wastewaters. This offers coal fired power plants a treatment option to increase internal recycle rates and decrease wastewater volume. The process is enabled by Saltworks' proprietary IonFlux monovalent anion selective ion exchange membranes that has 98% selectivity for monovalents, such as chloride, while rejecting multivalents, such as sulfate. It produces a non-scaling sodium and calcium chloride brine, achieving high recoveries without the need for expensive soda ash softening.

Saltworks Flex EDR Selective系统选择性地去除脱硫废水中的氯离子。该技术为燃煤电厂提供了一个提高内部水循环利用率并减少废水量的处理选择。该技术使用Saltworks专有创新的IonFlux单价阴离子选择性离子交换膜，该选择性离子交换膜对单价（如氯离子）具有98％的选择性，同时阻隔硫酸根类多价离子。该技术只产生不结垢的氯化钠和氯化钙浓水，实现高回收率，无需昂贵的纯碱软化。

FLEX EDR SELECTIVE PILOT TESTING
FLEX EDR SELECTIVE 单价选择性电渗析测试

The Flex EDR Selective technology is based on monovalent electrodialysis reversal (mEDR). As shown in Figure 1 below, mEDR can selectively remove monovalent chlorides while rejecting sulfates. As a result, it produces a non-scaling brine composed primarily of calcium chloride. The lack of sulfates entering the brine – blocked by the monovalent ion exchange membrane - removes the need for expensive chemical softening upstream.

Flex EDR Selective 技术基于单价离子选择性倒极电渗析（mEDR）。如下图 1 所示，mEDR 可以选择性地去除一价氯离子，同时阻隔硫酸根离子。因此它只产生由氯化钙组成的非结垢浓水。由于硫酸根被单价离子交换膜阻隔，无法进入浓水，从而无需进行昂贵的化学软化预处理。

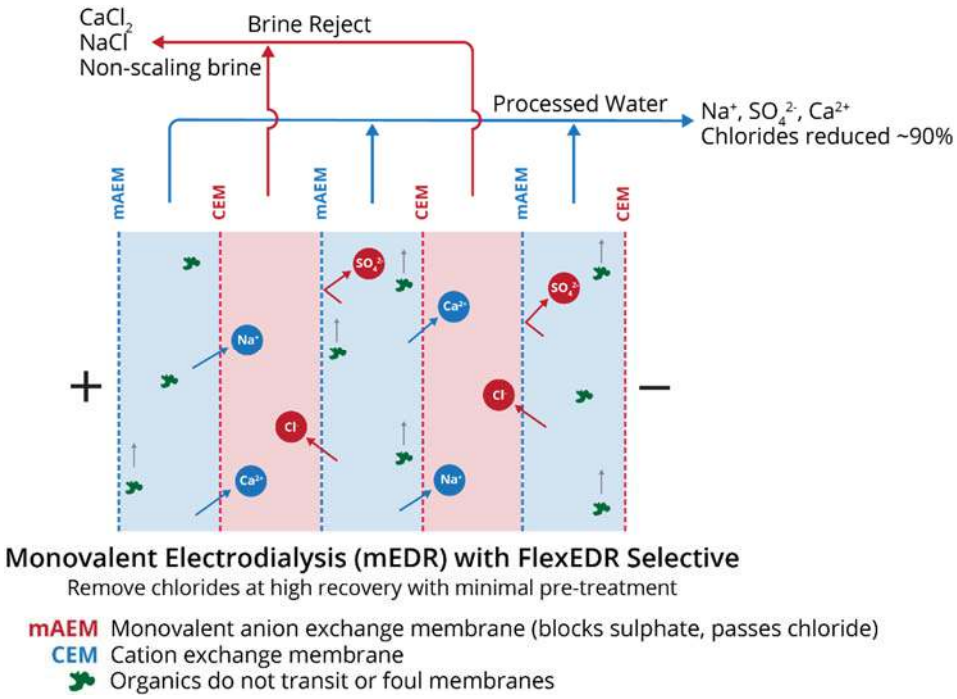

Figure 1: Flex EDR Selective Stack Diagram

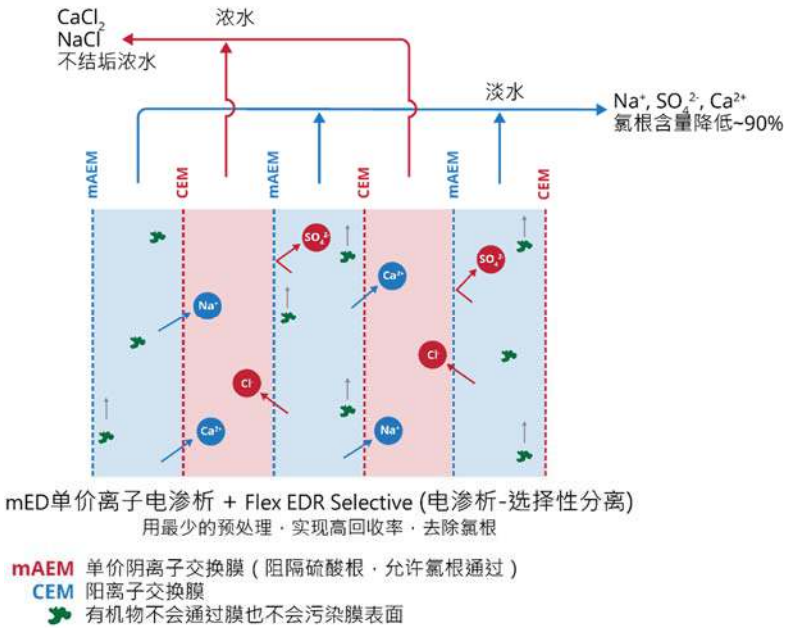

图1：Flex EDR Selective 膜堆示意图

The Flex EDR Selective off-site pilot test was completed with representative FGD wastewater that was collected directly from FGD scrubber tower without any pretreatment. The raw water as received was brown and turbid. Saltworks completed high pH pretreatment and prefiltration on

the FGD wastewater. No soda ash step was used nor is needed when employing monovalent electrodialysis. Pictures of the raw and after pretreatment is shown in Figure 2.

Flex EDR Selective场外测试的脱硫废水具有代表性，该废水直接从脱硫塔中收集，无任何预处理。收到的原水呈棕色混浊。Saltworks对该脱硫废水进行了pH值调节和简单过滤预处理。不需要进行纯碱软化，直接使用单价电渗析处理预处理的废水。
原水和预处理后的水样如图 2 所示。

Figure 2: FGD raw water (left) and after pretreatment and filtration (right)
图2：脱硫废水原水（左）和预处理和过滤后的脱硫废水（右）

The pretreated FGD water was piloted on Saltworks' Flex EDR Selective (or mEDR) small scale pilot plant (Figure 3). Full scale plants can be implemented as the foundation technology – electrodialysis - is not new and production systems are in placed as shown in Figure 4 below.

Saltworks 使用其小型 Flex EDR Selective（或 mEDR）测试设备（图 3）对预处理后的脱硫废水进行处理。该技术是是以电渗析为基础，大规模设备生产设施也已到位并可随时生产，如下图 4 所示。

Figure 3: Small Scale Flex EDR Pilot (left) and Stack (right)
图3：小型 Flex EDR 设备（左）和膜堆（右）

Figure 4: Full Scale Production of Electrodialysis Stacks and Membrane
图 4：大规模电渗析膜堆和膜生产

The simplified process flow diagram for the pilot is shown in Figure 5.
测试所用的简化工艺流程图如下图 5 所示。

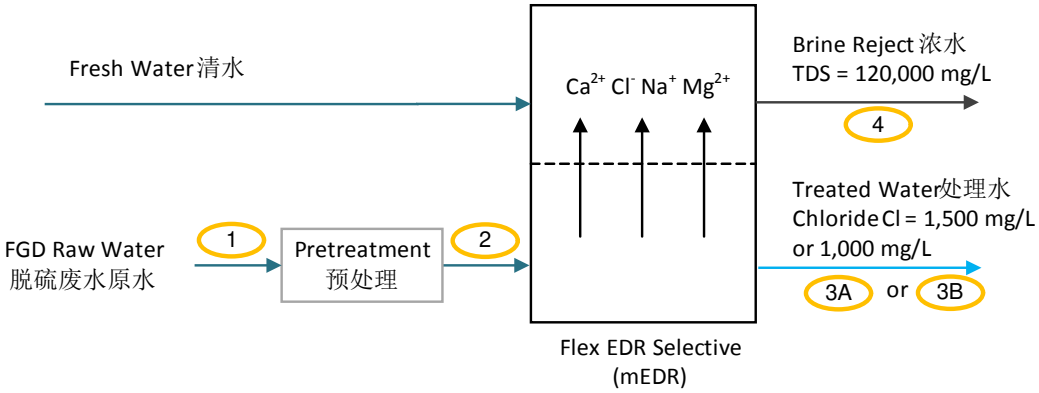

Figure 5: Flex EDR Selective Simplified Process Flow Diagram
图 5：Flex EDR Selective 简化工艺流程图

PILOT TEST RESULTS

测试结果

The key results from the Flex EDR Selective pilot test are summarized below with the detailed analytical results in Table 1.

- Achieved 90% recovery without soda ash softening due to mEDR keeping sulfates from entering into the brine.
- Demonstrated that mEDR can desalt from ~7,000 mg/L chlorides to any final chloride concentration. Both a final chloride concentration of 1,000 mg/L (88% chloride removal) and 1,500 mg/L (82% chloride removal) were achieved.
- Reached a brine of 127,000 mg/L TDS, close to that of evaporator brine concentration but with a lower cost membrane system. This brine could be directly solidified with fly ash and other solidification agents without the need for a crystallizer for ZLD.
- No soda ash softening of the raw water. The mEDR pilot concentrated calcium 7 times to 25,100 mg/L in the mEDR brine compared to the inlet concentration of 3,500 mg/L. This was only possible because of Saltworks' ultra-high monovalent anion selectivity ion exchange membranes maintaining the sulfate concentration in mEDR brine to less than 300 mg/L.

Flex EDR Selective测试的关键结果总结如下，详细分析结果见表1。

- 由于mEDR阻隔硫酸根进入浓水，因此在没有纯碱软化的情况下实现了90%的回收率。
- mEDR可以从~7,000 mg/L氯离子淡化至任何最终氯离子浓度。该测试实现了最终氯离子浓度1,000 mg/L（去除88%氯离子）和1,500 mg/L（去除82%氯离子）。
- 生成127,000 mg/L TDS的浓水，使用成本较低的膜系统，达到接近蒸发器浓水的浓度。该浓水可以用飞灰和其他固化剂直接固化，而不需要零排放结晶器。
- 未使用纯碱软化。与原水中钙浓度3,500 mg/L相比，mEDR浓水中的钙含量是原水中钙含量的7倍， 25,100 mg/L。由于Saltworks的超高单价阴离子选择性离子交换膜，mEDR浓水中的硫酸根浓度维持在低于300 mg/L。

Please note the bench test was not optimized, but to demonstrate technical feasibility and economics of the solution. The pretreated raw water calcium sulfate has reached saturated state. The sulfate concentration in the mEDR feed was higher than sulfate analysis result for the pretreated raw water (Table 1-column 2). It takes a few days for the sample to be analyzed by a 3rd party lab, some calcium sulfate precipitated out in the pretreated water during waiting period.

需要说明的是该测试还未经过工艺优化，仅为证明解决方案的技术可行性和经济性。经预处理的原水硫酸钙呈饱和状态。进入 mEDR 系统的实际水中的硫酸根含量高于预处理原水硫酸根分析值。第三方实验室需要花费几天时间对样品进行分析，预处理原水中饱和硫酸钙在等待分析期间稍有沉淀析出。

Additional pilot work was completed on other FGD projects. Results from the pilot test show similar results and are summarized below. Recovery of 87% is achieved without soda ash softening due to mEDR keeping sulfates from entering brine. Chloride is removed from 8,000 mg/L to 1,380 mg/L (84% chloride removal). A brine of 135,000 mg/L TDS is reached with calcium concentrated 8 times to 25,100 mg/L in the brine compared to the inlet concentration of 3,200 mg/L.

Saltworks 还完成了其他 FGD 脱硫废水项目的测试。其测试结果与上述测试类似，详细数据见表 2。无需苏打灰软化，mEDR 实现了 87%的回收率，并阻隔了硫酸盐进入浓水。废水中的氯离子从 8,000 mg/L 降至 1,380 mg/L（除去了 84%的氯），并产出高达 130,000 mg/L TDS 浓水。浓水中钙离子浓度从初始浓度 3,200 mg/L，浓缩了 8 倍至 25,100 mg/L。

COST
成本

Costs vary between projects and can be estimated based on project specifics. Comparing with conventional FGD desalination treatment process, the Flex EDR Selective will be lower capital and operating cost. This has been proven in the USA with up to 50% cost savings. The Flex EDR system doesn't require expensive soda softening step or complex treatments for discharge. The Flex EDR Selective process is a simple one step process for removing chloride in the water and producing high concentrated brine.

项目成本因个案而异，需要根据项目细节进行估算。与传统的脱硫废水脱盐工艺相比，Flex EDR Selective 降低了投资和运行成本。美国中试项目证明成本节省高达 50%。 Flex EDR 系统不需要昂贵的纯碱软化步骤或复杂的处理流程。Flex EDR Selective 工艺简单，一步可行，去除水中的氯离子并生成高盐浓水。

CONCLUSION
结论

The pilot testing demonstrated Flex EDR Selective can treat flue gas desulfurization wastewater by reducing chlorides and allowing for greater internal recycling. Total cost of ownership is reduced by up to 50% when compared to convention treatment process of soda ash softening followed by reverse osmosis and evaporators. Saltworks Flex EDR product platform is modular for easy site deployment and project integration. Concurrently a pilot in the USA on live FGD wastewater was underway.

试验测试表明，Flex EDR Selective 通过去除烟气脱硫废水中氯离子，允许废水更大的内部回用。与需要纯碱软化的反渗透和蒸发器常规处理工艺相比，总处理成本降低了 50%。Saltworks Flex EDR 产品是模块化的，可轻松实现设备组装。目前 Flex EDR Selective 正在美国一火力电厂对烟气脱硫废水进行现场中试。

Table 1: Water Chemistry Data for Pilot Test with China FGD Water
表 1：中国脱硫废水试验的水质数据

Parameter 参数	(1) FGD Raw Water 脱硫废水原水	(2) Pretreated Raw 预处理后原水	(3A) mEDR Treated Water mEDR处理后水 (<1000 mg/L Chlorides Cl)	(3B) mEDR Treated Water mEDR处理后水 (<1500 mg/L Chlorides Cl)	(4) mEDR Brine mEDR产生的浓水
Units:	mg/L	mg/L	mg/L	mg/L	mg/L
pH	6.95	3	3.6	3.59	2.99
Total Dissolved Solids总溶解固体含量	21200	17900	5340	6570	127000
Total Suspended Solids总悬浮固体	17	444	5	12	34
Total Hardness (as CaCO3)总硬度	13900	11300	3210	2910	77700
Total Organic Carbon总有机碳	194	174	154	152	30.7
Alkalinity (as CaCO3)碱度	164	<1	<1	<1	<1
Aluminum铝	0.5	<0.05	<0.05	<0.05	<0.10
Ammonia (as N) 氨	<0.1	0.12	<0.05	<0.05	1.13
Antimony锑	<0.005	<0.005	<0.005	<0.005	<0.010
Arsenic砷	0.005	<0.001	<0.001	0.002	<0.002
Barium钡	0.161	0.187	0.047	0.055	1.65
Beryllium铍	0.001	<0.0005	<0.0005	<0.0005	<0.0010
Bicarbonate (as CaCO3)碳酸氢根	164	<1	<1	<1	<1
Boron硼	62.7	18.4	19.9	20.3	10
Bromide溴	72.7	68.4	3.38	5.31	468
Cadmium镉	0.0816	0.0003	<0.0001	<0.0001	0.0008
Calcium钙	1030	3500	843	960	25100
Carbonate (as CaCO3)碳酸	<1	<1	<1	<1	<1
Chloride氯	6970	6560	835	1300	62700
Chromium铬	<0.005	0.029	0.008	0.01	0.144
Cobalt钴	0.204	<0.0005	<0.0005	<0.0005	<0.0010
Copper铜	0.012	0.006	0.024	0.019	0.654
Fluoride氟	32.2	4.1	3.64	3.38	3
Hydroxide (as CaCO3)氢氧根	<1	<1	<1	<1	<1
Iron铁	1.4	0.4	<0.1	<0.1	<0.5
Lead铅	0.0007	<0.0005	<0.0005	<0.0005	0.0034
Lithium锂	0.148	3.47	5.65	5.81	18.5
Magnesium镁	2750	627	195	215	3640
Manganese锰	31.4	<0.01	<0.01	<0.01	<0.05
Mercury汞	<1	<0.01	0.09	0.08	5
Molybdenum钼	0.016	0.005	0.006	0.007	0.016
Nickel镍	0.456	<0.005	<0.005	<0.005	0.026
Nitrate (as N)硝酸	6.23	3.15	0.101	0.222	37.8
Nitrite (as N)亚硝酸	1.1	1.55	<0.005	<0.005	<0.5
Phosphate (Ortho)磷酸	0.012	0.04	0.002	0.002	0.57
Potassium钾	30	31	10	11	183
Selenium硒	0.264	0.191	0.187	0.183	0.028
Silica (Reactive)二氧化硅	101	8.7	1.33	1.35	10.5
Silver银	<0.001	<0.001	<0.001	<0.001	<0.002
Sodium钠	245	241	170	172	1530
Strontium锶	11.9	12	3.06	3.56	103
Sulfate硫酸	4540	1790	2790	2170	297
Thallium铊	0.0033	0.0004	<0.0002	0.0005	<0.0004
Tin锡	0.0012	0.002	0.0077	0.0077	0.0228
Titanium钛	0.03	<0.01	0.02	<0.01	0.02
Uranium铀	0.0316	0.0032	0.0258	0.0265	0.006
Vanadium钒	<0.01	<0.01	<0.01	<0.01	<0.02
Zinc锌	1.13	<0.05	<0.05	<0.05	0.15

(*) the sulfate concentration in the actual mEDR feed was higher than the sulfate analysis result in the pretreated raw water (column 2) . Some calcium sulfate precipitated in the calcium sulfate saturated pretreated water during waiting for a third party analysis.

（*）进入 mEDR 系统的实际水中的硫酸根含量高于预处理原水硫酸根分析值， 预处理原水中饱和硫酸钙在等待第三方实验分析期间稍有沉淀析出。

Table 2: Water Chemistry Data for Additional Pilot Test
表 2：额外脱硫废水中试试验的水质数据

Parameter 参数	(1) FGD Raw Water 脱硫废水原水	(2) Pretreated Raw 预处理后原水	(3B) Treated Water 处理后净水 (<1500 mg/L Chlorides Cl)	(4) Brine 浓水
Units:	mg/L	mg/L	mg/L	mg/L
pH	6.02	3.12	3.49	2.89
Total Dissolved Solids总溶解固体含量	22800	21600	5280	135000
Total Suspended Solids总悬浮固体	122	16	10	31
Total Hardness (as CaCO3)总硬度	13900	11300	2910	77700
Total Organic Carbon总有机碳	173	176	152	30.7
Alkalinity (as CaCO3)碱度	164	<1	<1	<1
Aluminum铝	2.5	<0.05	<0.05	<0.10
Arsenic砷	0.005	<0.001	0.002	<0.002
Barium钡	0.161	0.187	0.055	1.65
Bicarbonate (as CaCO3)碳酸氢根	164	<1	<1	<1
Boron硼	77.7	19.4	21.3	11
Bromide溴	72.7	68.4	5.31	468
Cadmium镉	0.01	0.0003	<0.0001	0.0008
Calcium钙	1120	3200	960	25100
Carbonate (as CaCO3)碳酸	<1	<1	<1	<1
Chloride氯	8020	7950	1320	73100
Chromium铬	<0.005	0.029	0.01	0.144
Fluoride氟	76.2	8.1	7.18	8.2
Hydroxide (as CaCO3)氢氧根	<1	<1	<1	<1
Iron铁	1.4	0.4	<0.1	<0.5
Lead铅	0.0007	<0.0005	<0.0005	0.0034
Magnesium镁	4020	1027	344	5962
Manganese锰	31.4	<0.01	<0.01	<0.05
Mercury汞	<1	<0.01	0.08	5
Molybdenum钼	0.016	0.005	0.007	0.016
Nickel镍	0.456	<0.005	<0.005	0.026
Nitrate (as N)硝酸	87.2	83.1	1.2	1024
Nitrite (as N)亚硝酸	2.1	1.75	<0.005	<0.5
Phosphate (Ortho)磷酸	0.012	0.04	0.002	0.57
Potassium钾	30	31	11	183
Selenium硒	0.264	0.191	0.183	0.028
Silica (Reactive)二氧化硅	199	9.7	1.38	10.9
Sodium钠	1240	1220	470	7780
Strontium锶	11.9	12	3.56	103
Sulfate硫酸	5640	1820	1736	128
Zinc锌	1.13	<0.05	<0.05	0.15

