PROJECT SUMMARY
项目摘要

Saltworks Technologies Inc. (Saltworks) completed an end-to-end zero liquid discharge (ZLD) and zero air emission off-site pilot to treat concentrated reverse osmosis leachate brine from a municipal waste incineration plant in China.

Saltworks Technologies Inc.（Saltworks）完成了端到端零排放（ZLD）和零气体排放场外中试，处理来自中国城市垃圾焚烧厂的反渗透浓水。

The site presently treats raw leachate with biological treatment, conventional RO and disc tube RO (DTRO) systems. The DTRO brine reject is sent to the incinerator for final evaporation. However, the DTRO brine volume reduces the capacity of their incinerator to process solid waste and the client is preparing for new regulations that could forbid this practice. The project objective was therefore to eliminate the wastewater volume by producing both clean water and solids at the lowest total cost of ownership.

该工厂目前用生物处理，常规反渗透（RO）和碟管式反渗透（DTRO）系统处理原渗滤液。将DTRO浓水送至焚烧炉进行最终蒸发。然而，DTRO浓水量降低了焚化炉处理固废的能力，客户正在准备可能禁止这种做法的新法规。因此，该项目目标是以最低的总处理成本生产净水和固废来最小化渗透液废水量。

The leachate DTRO brine was first concentrated by Saltworks using an advanced high recovery reverse osmosis unit with scalant removal, followed by crystallization in a waste heat powered evaporator. More specifically, the treatment train consisted of BrineRefine advanced chemical softening, Xtreme Reverse Osmosis (XRO), and a low temperature AirBreather evaporator crystallizer.

渗滤液DTRO浓水首先被预处理去除结垢物质，再由Saltworks的先进高回收率反渗透系统进行浓缩，然后在蒸发器中利用废热蒸发结晶。更具体地，处理系统包括BrineRefine先进的化学软化，Xtreme Reverse Osmosis（XRO）高回收反渗透和AirBreather低温蒸发结晶器组成。

The results showed that Saltworks' BrineRefine-XRO-AirBreather process achieved:

- Elimination of scaling compounds by a smart, compact, and modular chemical softening BrineRefine, enabling extreme recoveries by XRO.
- Production of high quality freshwater from a scaling and organic laden wastewater by XRO and AirBreather.
- BrineRefine-XRO reduced the wastewater volume by half, decreasing the capacity and cost of the more expensive thermal system.

- Zero liquid discharge solids produced by a low temperature AirBreather evaporator crystallizer built from non-scaling and non-fouling engineered plastics with intelligent automated self-cleaning systems.

结果表明，Saltworks的BrineRefine-XRO-AirBreather工艺实现了：

- 通过智能，紧凑和模块化的BrineRefine化学软化去除结垢物，实现XRO反渗透的极高回收率。
- 通过XRO和AirBreather从结垢和富含有机物的废水中生产高质量净水。
- BrineRefine-XRO将废水量减少了一半，降低了更昂贵的蒸发系统的处理量和成本。
- AirBreather低温蒸发结晶器生产零排放固体。AirBreather由不结垢和无污染的工程塑料制成，具有智能自动化自清洁系统。

Saltworks developed a complete process to treat the RO brine to solids consisting of: BrineRefine, XRO (1200 psi), and AirBreather. The process flow diagram (PFD) is shown in Figure 1 below, alongside pictures of the water from each unit operation in Figure 2. A high-level description of each unit operation is included below with a link to additional external information:

Saltworks开发了一种将反渗透浓水处理成固体的完整工艺，包括：BrineRefine，XRO（1200 psi）和AirBreather。下图1展示了工艺流程图，图2展示了各工艺处理后水样图片。以下是每项工艺的简要描述，并附有额外信息的链接：

- BrineRefine is an automated, compact, and modular chemical softening system. It reduces chemical softening costs with precision dosing, intelligent controls and a simple solids management system. BrineRefine entirely removes RO membrane fouling risk associated with aluminum gels common from chemical softening agents, by not using coagulants or flocculants.

- BrineRefine是一种自动化，紧凑型和模块化的化学软化系统。它通过精确计量，智能控制和简单的固体管理系统降低了化学软化成本。通过不使用凝结剂或絮凝剂，BrineRefine完全消除了与化学软化剂，如常见的铝凝胶相关的反渗透膜污染风险。

- XRO is a next-generation brine concentrator based on reverse osmosis that achieves extreme freshwater recoveries. Xtreme RO enabled by BrineRefine pushes the osmotic pressure limits of reverse osmosis without scaling. For this project only XRO (1200 psi) was tested. Due to the low full scale plant flows of 150 m^3/day, further concentrating the XRO (1200 psi) with XRO (1800 psi) did not provide any further economical benefit.

- XRO是基于反渗透的新一代浓水浓缩系统，可实现极高的净水回收率。 BrineRefine帮助Xtreme RO达到反渗透的渗透压极限，而不会结垢。对于该项目，仅测试了XRO (1200

psi)。由于仅150立方米/天的低处理量，XRO (1800 psi) 进一步浓缩XRO (1200 psi) 浓水，不会提供进一步经济性。

- AirBreather is a single effect, low temperature evaporator-crystallizer. It comes in either an open or closed to atmosphere option. AirBreather best fits applications that have low cost thermal energy available (e.g., waste heat at incinerator site) and the economics are driven by wastewater volume reduction rather than water recovery. For this project a closed AirBreather was selected due to site sensitivities of a water vapor plume or other air emission risks. In this way, no leachate water contacts atmosphere.

- AirBreather是一种单效低温蒸发结晶器。AirBreather有开放式和封闭式两种选择。AirBreather最适合具有低成本热源的项目（例如，焚烧炉废热），并且其经济性由降低废水量驱动，而不是由水回用驱动。对于该项目，由于水蒸汽或其他空气排放风险的敏感性，封闭的AirBreather被选中，确保渗滤液不会与大气接触。

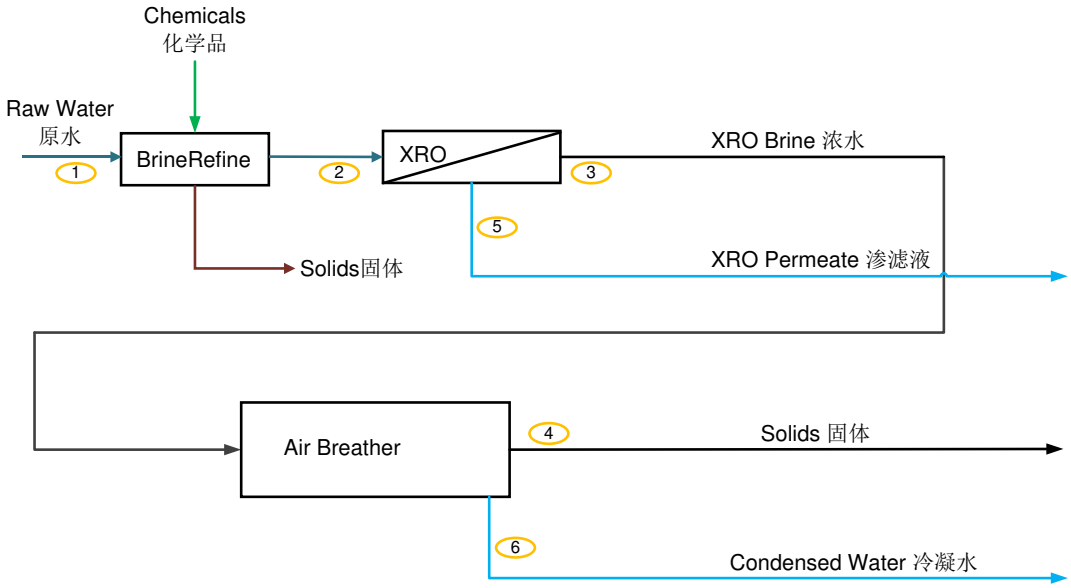

Figure 1: Simplified Process Flow for End-to-End Concentrated Leachate Treatment
图1：端到端浓缩渗滤液处理的简化工艺流程

Figure 2: (1) Raw Water, (2) After BrineRefine, (3) XRO Brine, (4) AirBreather Solid, (5) XRO permeate and (6) AirBreather Condensed Water (From left to right)
图2：（1）原水，（2）BrineRefine处理后浓水，（3）XRO浓水，（4）AirBreather固体，（5）XRO渗透液和（6）AirBreather冷凝水（从左到右）

PILOT TESTING
中试测试

The off-site pilot test was completed with representative leachate RO/DTRO brine sample that was collected directly from a China landfill incinerator site. Pictures of the equipment are included in Figure 1 (pilot scale BrineRefine and XRO) and Figure 2 (full scale AirBreather).

使用代表性的渗滤液RO/DTRO浓水样品完成了场外中试，该样品直接从中国垃圾填埋焚烧场收集。设备图片如图1（中试规模BrineRefine和XRO）和图2（全尺寸AirBreather）。

Figure 1: BrineRefine (left) and XRO (right) Pilots
图1：BrineRefine（左）和XRO（右）中试设备

Figure 2: AirBreather Evaporator Crystallizer
图2：AirBreather蒸发结晶器

PILOT TEST RESULTS
中试测试结果

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

中试测试的结果总结如下，详细分析结果见表1。

- BrineRefine reduced scaling ions in the leachate RO brine as follows, making the water "safer" for processing by a downstream high recovery RO:
  - Silica: 128 to 8.3 mg/L.
  - Iron: 4 to 0.3 mg/L
  - Manganese: 0.31 to <0.01 mg/L
  - Calcium: 440 to 31.3 mg/L
  - Carbonate: pH adjustment to pH 6.5 with Hydrochloride acid
  - Some organics were also removed, however organic fouling of downstream RO must be carefully managed through use of XRO technology

- BrineRefine降低了渗滤液RO浓水中的结垢离子，使得处理水无结垢风险，保障下游高回收率反渗透顺利运行：
  - 二氧化硅：128至8.3 mg/L
  - 铁：4至0.3 mg/L
  - 锰：0.31至<0.01 mg/L
  - 钙：440至31.3 mg/L
  - 碳酸盐：用盐酸将pH调节至pH 6.5
  - 一些有机物也被去除，但下游的有机污染必须通过使用XRO技术进行精确控制

- XRO (1200 psi) operated at 50% recovery, reducing the leachate RO brine by half and producing a 64,000 mg/L total dissolved solids (TDS) brine. Higher TDS concentration could have been achieved but was left for future work. The XRO (1200 psi) operated reliably even in the presence of organics (total organic carbon at 771 mg/L) due to XRO proprietary self-cleaning system as described here. XRO (1200 psi) permeate was < 500 mg/L TDS.

- XRO（1200 psi）在50％回收率下运行，将渗滤液RO浓水减少一半，产生64,000 mg/L总溶解固体（TDS）浓水。XRO可以实现更高的TDS浓度，但留待以后测试。由于XRO专有自清洁系统，XRO（1200 psi）即使在存在高有机物（总有机碳为771 mg/L）的情况下也能可靠运行。 XRO（1200psi）渗透液 <500 mg/L TDS。

- The AirBreather produced solids and a condensed water with 8 mg/L TDS from the XRO (1200 psi) brine. The automated self cleaning systems, and other AirBreather features described here, maintained reliable operation even at brine concentrations with TDS of 460,000 mg/L and TOC of 5000 mg/L. When the brine reached 400,000 mg/L TDS, foaming occurred but was suppressed with the addition of a defoamer.

- AirBreather处理XRO（1200 psi）浓水，生成固体和 8 mg/L TDS冷凝水。自动化自清洁系统和其他AirBreather功能（链接）帮助AirBreather即使在460,000 mg/L TDS， 5000 mg/L TOC高盐水浓度下也能保持可靠运行。当盐水达到400,000 mg/L TDS时，发生起泡但是可以通过添加消泡剂来抑制。

- A volatile organic compounds (VOCs) analysis was completed on the raw RO/DTRO leachate. Table 2 summarizes the results and show that there was no detectable concentration of VOCs except for chloroform at 1 ppb.

- 原始RO / DTRO渗滤液的挥发性有机化合物（VOC）分析如表2。结果表明除了1 ppb的氯仿外，没有可检测到的VOC浓度。

- For this project, the site did not want a water vapor plume discharge and hence opted for a closed AirBreather. That said, our open AirBreather has a built-in air emissions management system that removes VOCs, ammonia, and particulate matter to ensure air emission standards are met.

- 对于该项目，客户不希望水蒸汽排出，因而选择了封闭的AirBreather。即使如此，我们的开放式AirBreather具有内置的空气排放管理系统，可以去除VOC，氨和颗粒物质，以确保达到空气排放标准。

CONCLUSION
结论

The pilot testing demonstrated BrineRefine, XRO, and AirBreather can offer an end-to-end zero liquid discharge treatment system. BrineRefine enables brine volume reduction by a XRO membrane system on a highly scaling and organic laden leachate wastewater. This reduces the size and costs of thermal systems when zero liquid discharge is required and could save up to 50% on total cost of ownership. Plant costing is disclosed in a separate document.

中试测试表明，BrineRefine，XRO和AirBreather可以提供端到端的零排放处理系统。BrineRefine帮助XRO膜系统处理高度结垢和高有机负载的渗滤液废水，减少浓水体积。当需要实现零排放时，XRO减小了蒸发系统的尺寸和成本，从而节省高达50％的总处理成本。设备成本在另外的文件中公开。

Table 1: BrineRefine-XRO-AirBreather Pilot Detailed Water Chemistry Results

表1：BrineRefine-XRO-AirBreather中试详细的水质分析结果

Parameter 参数	(1) Raw Water 原水	(2) After BrineRefine 预处理后水	(3) XRO Brine XRO浓水	(4) AirBreather Brine AirBreather浓水	(5) XRO Permeate XRO渗透液	(6) AirBreather Condensed Water 冷凝水
Units:	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
pH	7.88	6.59	6.96	6.36	7.07	7.9
Total Dissolved Solids总溶解固体量	32800	32500	64600	460000	400	8
Total Suspended Solids总悬浮固体	121	10	8	352	<2	<2
Total Hardness (as CaCO3)总硬度	4120	1230	-	-	3	1
Total Organic Carbon总有机碳	453	388	771	4940	1.1	12.7
Total Oil and Grease	-	-	-	-	-	-
Alkalinity (as CaCO3)碱度	4340	237	475	400	7	20
Aluminum铝	<0.05	<0.05	0.19	1	0.006	0.061
Ammonia (as N) 氨	53.4	50.7	96.3	498	0.78	5.66
Antimony锑	0.143	0.127	0.19	1.67	<0.0005	0.0006
Arsenic砷	0.057	0.014	0.022	0.19	<0.0001	0.0001
Barium钡	0.043	0.025	0.048	0.79	0.044	0.0123
Beryllium铍	<0.0005	<0.0005	<0.0005	<0.005	<0.00005	<0.00005
Bicarbonate (as CaCO3)碳酸氢根	4340	237	475	400	7	20
Boron硼	4.6	3.63	3.64	39.6	0.331	0.101
Bromide溴	4.9	7.7	16	111	<0.05	<0.05
Cadmium镉	<0.0001	0.0002	0.0004	<0.001	<0.00001	<0.00001
Calcium钙	440	31.3	75	1030	0.93	0.21
Carbonate (as CaCO3)碳酸	<20	<1	<1	<100	<1	<1
Chloride氯	10400	12700	22900	169000	89.5	4.7
Chromium铬	0.197	0.164	0.285	2.18	<0.0005	<0.0005
Cobalt钴	0.196	0.16	0.255	2.21	<0.00005	0.00013
Copper铜	0.079	0.05	0.09	1.03	0.0007	0.0011
Fluoride氟	<0.2	0.4	<2	<20	0.03	<0.02
Hydroxide (as CaCO3)氢氧根	<20	<1	<1	<100	<1	<1
Iron铁	4	0.3	<1	14	<0.01	<0.01
Lead铅	0.001	0.001	0.0014	0.031	<0.00005	<0.00005
Lithium锂	1	1.94	3.3	34.4	0.0127	0.001
Magnesium镁	733	280	495	4340	0.25	0.14
Manganese锰	0.31	<0.01	<0.1	0.4	<0.001	0.003
Mercury汞	<0.1	0.1	0.3	1	<0.01	<0.01
Molybdenum钼	0.124	0.129	0.191	1.92	0.0003	0.0003
Nickel镍	1.07	1.01	1.58	13.9	0.001	<0.0005
Nitrate (as N)硝酸	1360	1470	2770	19100	37	0.501
Nitrite (as N)亚硝酸	3.3	2.93	4.3	<5	<0.005	1.92
Phosphate (Ortho)磷酸	2.15	0.05	0.03	-	0.004	0.005
Potassium钾	4660	4330	8950	75600	49.1	1.8
Selenium硒	0.01	0.029	0.024	0.15	<0.0005	<0.0005
Silica (Reactive)二氧化硅	128	8.3	17.6	131	<0.01	<0.01
Silver银	<0.001	<0.001	<0.001	<0.01	<0.0001	<0.0001
Sodium钠	7090	6400	13800	113000	86.4	3
Strontium锶	3.46	0.164	0.302	6.94	0.0007	0.0016
Sulfate硫酸	1050	1150	2180	16300	1.1	1.2
Thallium铊	<0.0002	<0.0002	<0.0002	<0.002	0.00006	0.00015
Tin锡	0.0082	0.0041	0.0057	0.074	0.00015	0.00822
Titanium钛	0.07	0.02	0.03	0.3	<0.001	0.001
Uranium铀	0.0001	0.0037	0.0063	0.043	<0.00001	<0.00001
Vanadium钒	0.13	0.09	0.16	1.2	<0.001	<0.001
Zinc锌	0.44	0.07	0.1	1.5	0.005	0.017

Table 2: Raw Water VOC Scan Results
表2：原水VOC测试结果

Sample Date取样日期	**Jan 03, 2019 2019年1月3日**
Parameter	**DTRO Brine VOC Scan DTRO浓水VOC数据**
Unit:	µg/L
Chloromethane氯甲烷	<1
Vinyl Chloride氯乙烯	<1
Bromomethane溴甲烷	<1
Chloroethane氯乙烷	<1
Trichlorofluoromethane三氯氟甲烷	<1
Acetone丙酮	<10
1,1-Dichloroethylene1,1-二氯乙烯	<1
Dichloromethane二氯甲烷	1.00
Methyl tert-butyl ether (MTBE)甲基叔丁基醚	<1
2-Butanone (MEK) 2-丁酮	<10
trans-1,2-Dichloroethylene 反式-1,2-二氯乙烯	<1
1,1-Dichloroethane 1,1-二氯乙烷	<1
cis-1,2-Dichloroethylene 顺式-1,2-二氯乙烯	<1
Chloroform 氯仿	1.00
1,2-Dichloroethane 1,2-二氯乙烷	<1
1,1,1-Trichloroethane 1,1,1-三氯乙烷	<1
Carbon Tetrachloride 四氯化碳	<0.5
Benzene 苯	<0.5
1,2-Dichloropropane 1,2-二氯苯	<1
Trichloroethene 三氯乙烯	<1
Bromodichloromethane 一溴二氯甲烷	<1
trans-1,3-Dichloropropene反式1,3-二氯丙烯	<1
4-Methyl-2-pentanone (MIBK)4-甲基-2-戊酮	<10
cis-1,3-Dichloropropene顺式1,3-二氯丙烯	<1
1,1,2-Trichloroethane1,1,2-三氯乙烷	<1
Toluene甲苯	<0.5
Dibromochloromethane二溴	<1
1,2-Dibromoethane1,2-二溴乙烷	<0.3
Tetrachloroethylene四氯乙烯	<1
1,1,1,2-Tetrachloroethane1,1,1,2-四氯乙烷	<1
Chlorobenzene氯苯	<1
Ethylbenzene乙苯	<0.5
m&p-Xylene对二甲苯	<0.5
Bromoform三溴甲烷	<1
Styrene苯乙烯	<0.5
1,1,2,2-Tetrachloroethane1,1,2,2-四氯乙烷	<0.8
o-Xylene邻二甲苯	<0.5
1,3-Dichlorobenzene1,3-二氯苯	<0.5
1,4-Dichlorobenzene1,4-二氯苯	<0.5
1,2-Dichlorobenzene1,2-二氯苯	<0.5
1,2,4-Trichlorobenzene1,2,4-三氯苯	<1
VH	<100
VPH	<100
Total Xylenes总二甲苯	<1
Total Trihalomethanes总三卤甲烷	<2
1,3-Dichloropropene (cis + trans)1,3-二氯丙烯（顺式+反式）	<1

