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Energy Efficient Waste Heat Coupled Forward Osmosis for Effluent Water Management at Coal-Fired Power Plants
Project Number DE-FE0031551

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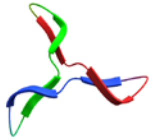
DOE/NETL Project Manager: Mr. Charles Miller

U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

Section 1

- *Terminology*
- *Objectives*
- *Alignment with DOE*
- *State-of-Art Comparison*



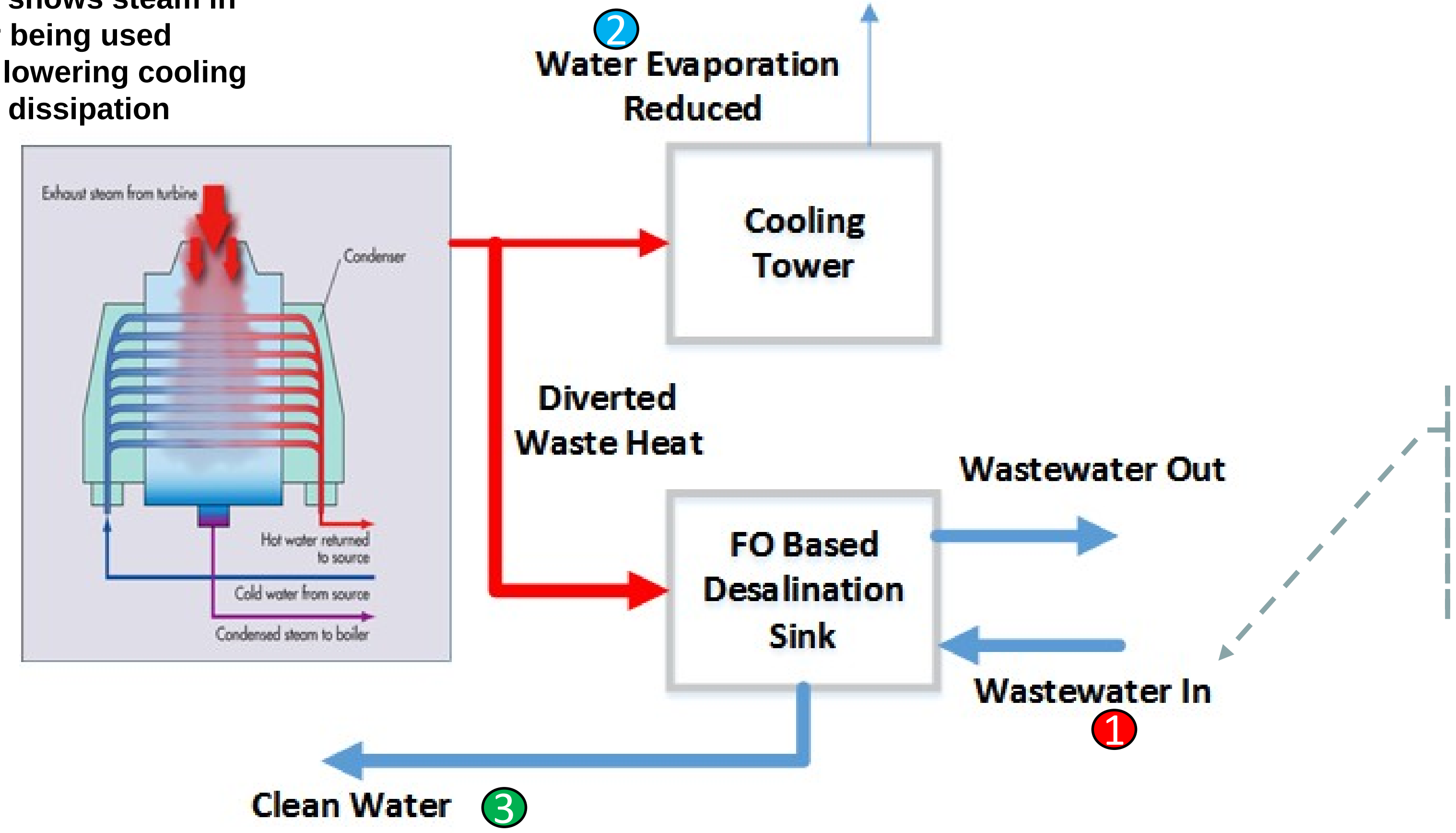
Terminology

- Power plant effluents: **FGD scrubber blowdown**; cooling tower blowdown; ash transport water, etc.
- Management: Water **reuse/recycling**; Compliance with **ELG /CCR**;
- Waste Heat Coupled: **Treatment** methods driven by flue gas or condenser heat or other sources
- Forward Osmosis: **Thermal energy driven osmotic** membrane based process operating at **ambient** **pressure/temperature;**
- Energy Efficient: Targets: **<200 kJ/kg thermal** of water produced & <**3.6 kWh/m^3**

Waste Heat to Water in Power Plants

Schematic shows steam in condenser being used elsewhere lowering cooling tower heat dissipation

Other sources of waste heat can also be used; e.g. Flue gas



FGD scrubber blow down, Ash pond effluent, Municipal effluent

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Project Objectives

- Overall goal
  - Evaluate a transformational low energy (<200 kJ/kg water) waste heat coupled forward osmosis (FO) based water treatment system (the Aquapod ©), to manage effluents, meet cooling water demands and achieve water conservation in complex and unique environment of a power plant environment

- Specific objectives
  - To map the available wastewater sources and waste heat in a coal-fired power plant of 2009 vintage.
  - To establish the ***technical*** and ***economic*** **feasibility** of utilizing the Aquapod© process to recover at least 50% usable water from degraded water sources such as FGD blowdown, other proximal wastewater.
  - To evaluate the ability of FO operational modes to handle highly fouling stream such as FGD blowdown without extensive softening.

Alignment with DOE Goals

Current Project aligns with

DE-FOA-0001686/ AOI 5 Effluent Water Management at Coal-Fired Energy Plants goals of

- understanding the overall water balances, understand constituents of concern, and reduce overall treatment requirements
- promoting innovative effluent water management practices at coal-fired energy plants.
- developing water treatment and reuse methods that employ low energy or waste heat solutions

Aquapod© & Current State-of-Art

Aquapod

- Uses heat/waste heat as opposed to electrical energy
- Requires minimal pretreatment
- Low energy consumption; thermal

<200 kJ/kg; electrical <3.6 kWh/m^3

- Simple equipment – primarily membrane modules, mixer settler systems
- Benign chemicals
- Range of TDS: 10-12% NaCl

Other technologies

- RO, NF – use electrical energy
- RO, NF need more extensive pretreatment for high fouling streams such as FGD scrubber blowdown
- Membrane distillation/ ammonium carbamate based FO systems have energy consumption in the range of 400 – 1200 kJ/kg
- Ammonium carbamate FO systems use ammonia, more complex equipment.

Section 2

230 MW Coal Fired Power Plant

- *Water Use/Effluent In Power Plants*
- *Waste Heat Availability*
- *Conclusions*

Mapping Wastewater

230 MW Coal Fired Power Plant

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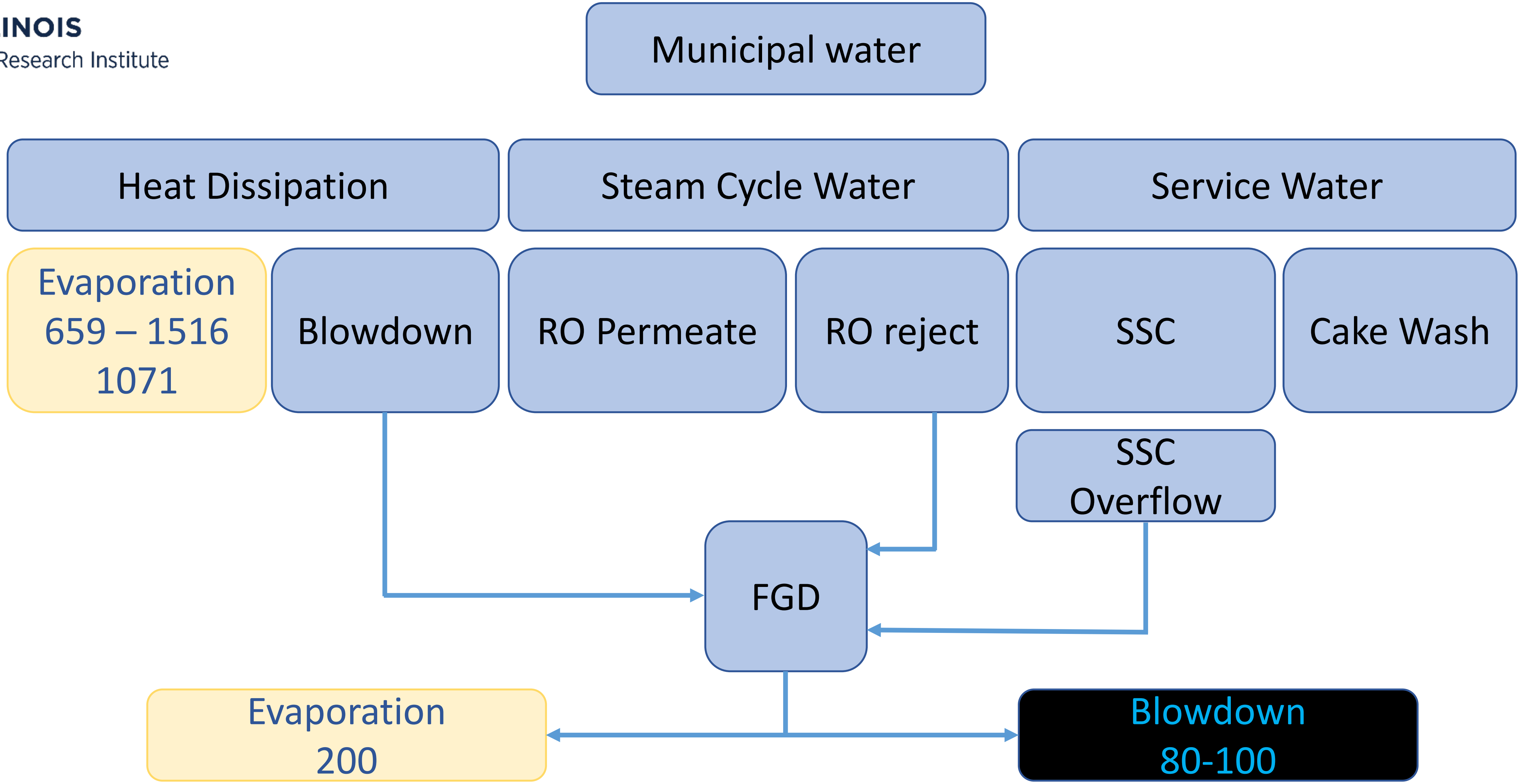

Units: gpm
SSC: Submerged scraper conveyor
1071 – median value of evaporation in cooling tower

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Potential Wastewater Sources for FO Treatment

Wastewater Source	Potential Volume Available GPM	Comments	Ability to meet cooling water demands
FGD Blowdown	**80-100**	Depends on chloride level set point in scrubber; problematic from a regulatory standpoint; high fouling stream	~ **2.5-7.5%** [a]
On-site WWTP	(4.29 MGD/~3000 gpm)		**100 %**
Wastewater from nearby municipal wastewater treatment plant	(10 MGD Design Average Flow/~ 7000 gpm)		**100 %**

[a] FGD blowdown assumed to be between 80 and 100 gpm; 50% reuse of this stream assumed; cooling tower make up water needs are taken to be 659 – 1516 gpm (100 MWh – 230 MWh)

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Wastewater Characteristics Relevant for FO

Stream Description	GPM	Comments	Total Dissolved Solids mg/L	Osmotic Pressure psia	Minerals Exceeding Saturation Potential Scalants
FGD blowdown water	80-100	To municipal wastewater treatment plant	10,000 -12,200	83	Calcite, Fluorite, Barite, **Gypsum**, Bayerite, Sellaite, Siderite, Brucite
Inlet to on-site wastewater plant	~3000	Currently treated and discharged to Lake; water not used for current unit	320	3	Bayerite, Barite
Secondary Influent from Municipal WWTP	~7000	Available within 10 miles from the IL Power Plant	570	7	Calcite, Siderite, Bayerite

Mapping Waste Heat

230 MW Coal Fired Power Plant

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Waste Heat Sources in IL PP

Stream	Temperature Available °F (°C)	Heat Quantity (MMBTU/Hr)	Quantity of Water Generated by Evaporation assuming 1000 BTU/lb for evaporation
Condenser water	106 (41)	921	Too low for evaporation without excessive vacuum.
Flue gas at Air Preheater Outlet	**300 (149)**	**52**	Approximately 100 gpm of water can be evaporated using the heat in flue gas;
Bottom Ash Overflow Water	140 (60)	2.75	Insignificant

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Section 2: Conclusions

- Waste heat available in flue gas sufficient to desalinate ~1000 gpm of wastewater through low energy FO process (200 kJ/kg)
- Part of the waste heat in condenser water can be used in the FO process as well

- FGD scrubber blowdown most troublesome from treatment and regulatory point; of greatest interest to utility; can satisfy only small portion of cooling tower demands; best suited for FO due to high fouling nature
- Other wastewater (onsite/offsite) can supplement cooling tower requirements

Section 3

230 MW Coal Fired Power Plant

Aquapod – Working Principle

FGD-FO Data

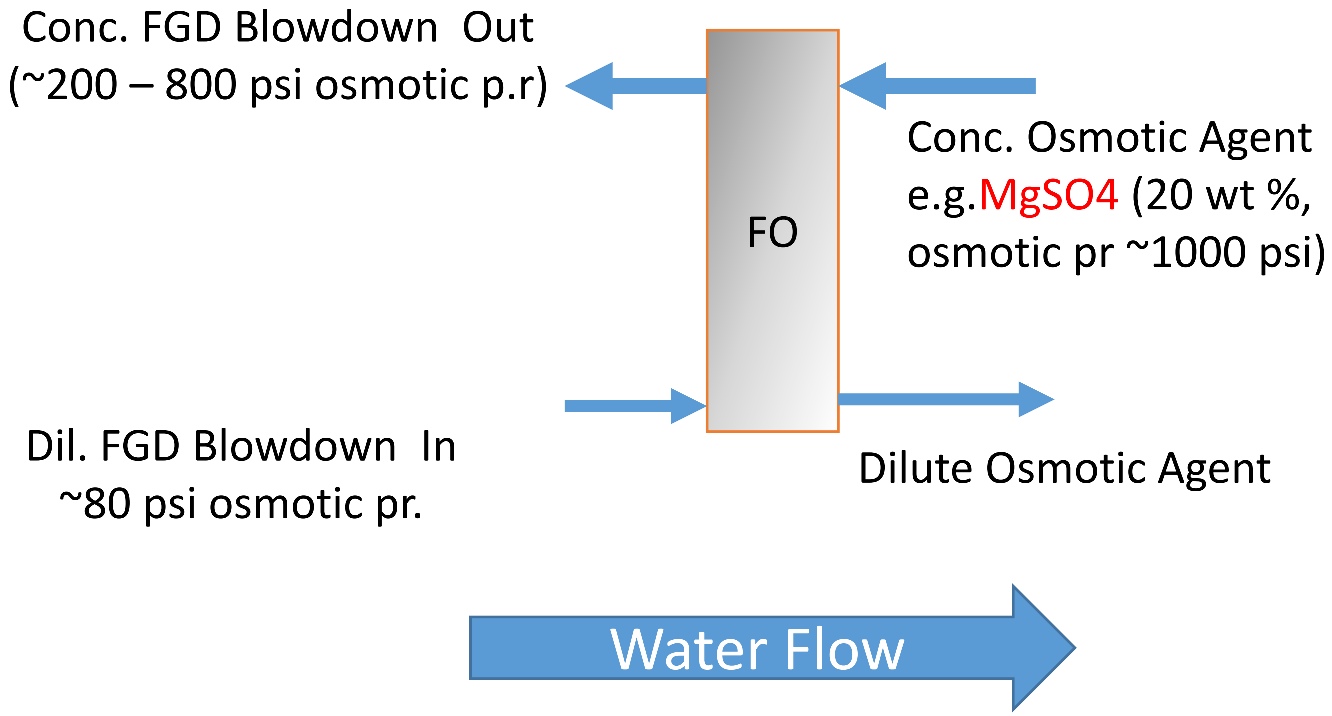
Salt-Polymer Selection Considerations

Summary

Next Steps

Aquapod FO Process Principle

Step 1: Conventional FO Using Inorganic Salt



$MgSO_4$ used as osmotic agent in this project

- Nontoxic
- Noncorrosive
- Adequate osmotic pressure (upto 1800 psi)
- Low reveres salt flux
- Cheap

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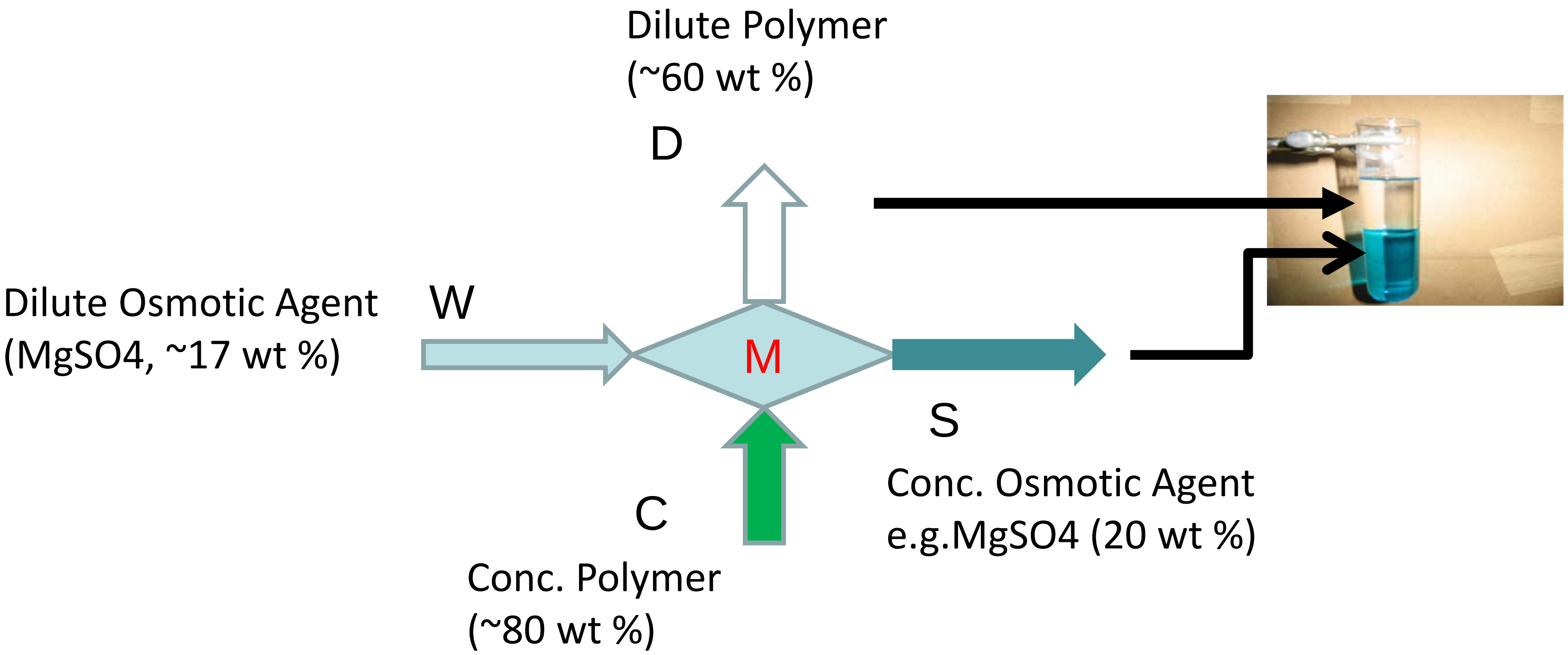
Aquapod FO Process Principle

Step 2: Polymer EXTRACTS water from MgSO4 solution



Polymer and MgSO4 are insoluble
Form two phases at room temperature

Streams D and S are in chemical equilibrium
i.e., osmotic pressure of streams are same

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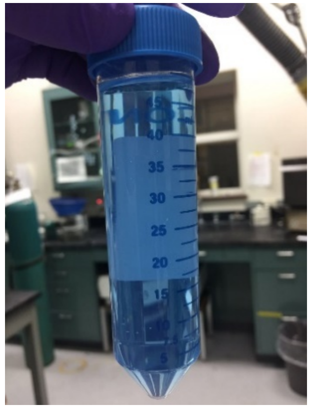
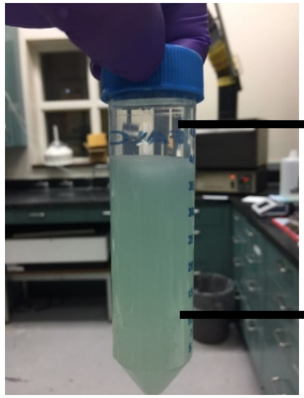
Aquapod FO Process Principle

Step 3: Heat polymer to extract water



Dilute Polymer
(~60 wt %)

Heat above cloud point
(e.g., 80 C)



Water

Conc. Polymer
(~80 wt %)

Concentration of polymer in polymer phase is a function of temperature

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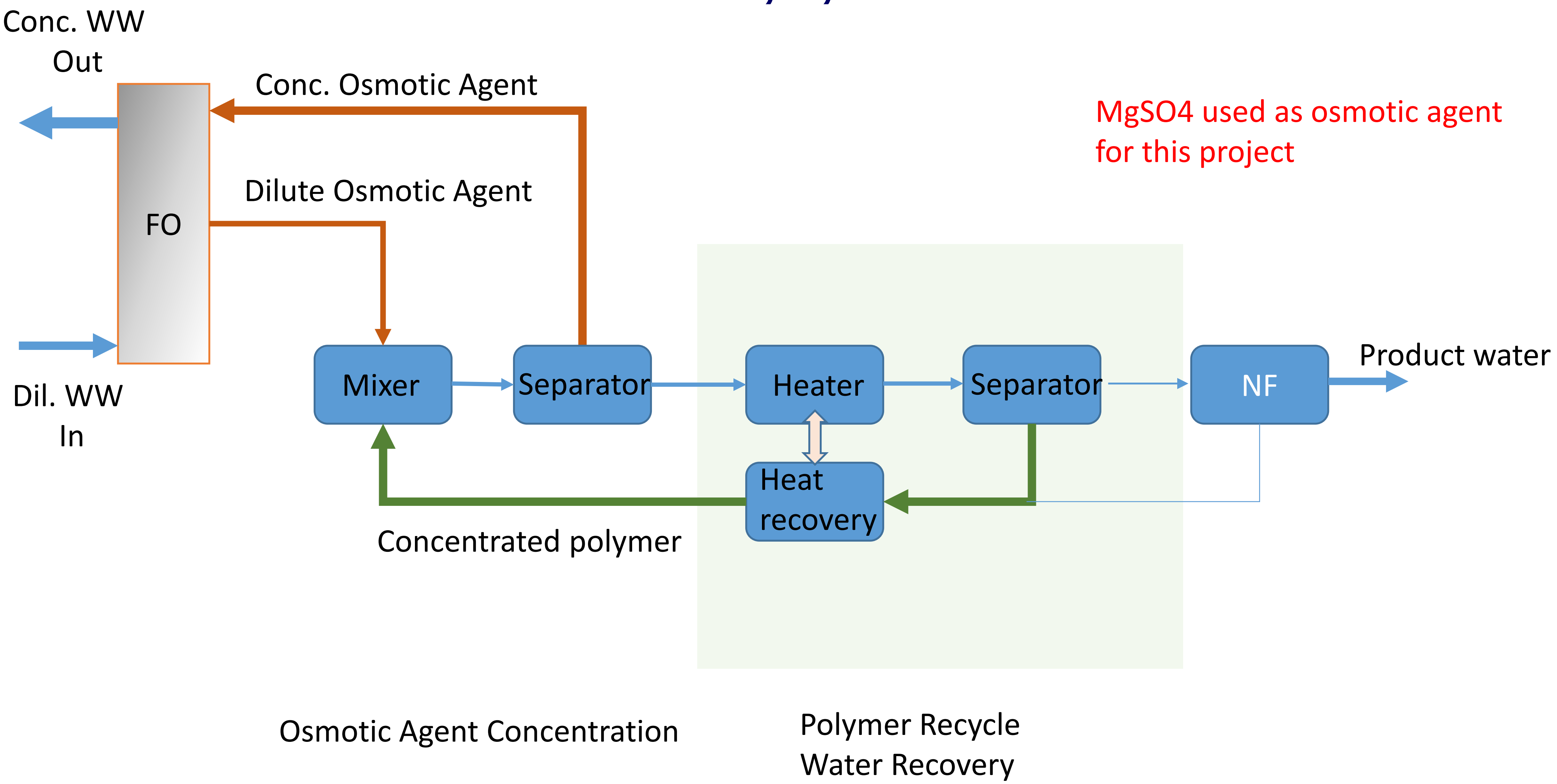
Aquapod FO Flowsheet
1, 2, 3…

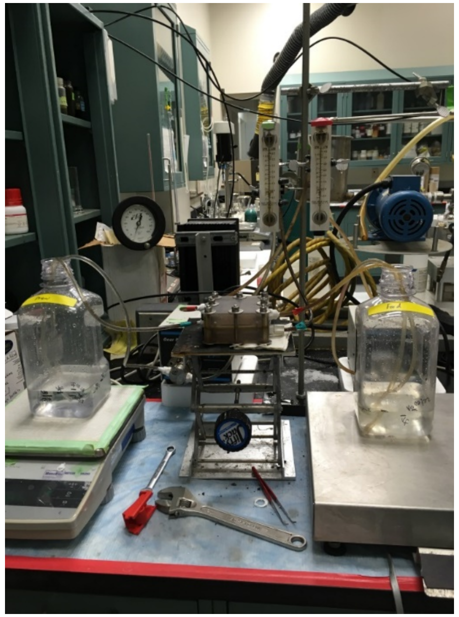


MgSO4 used as osmotic agent for this project

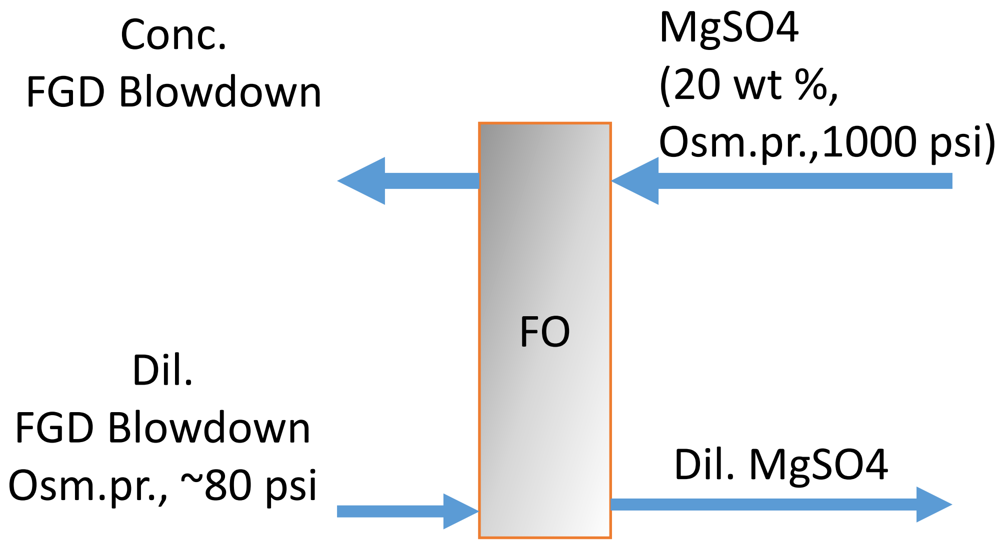
Section 3

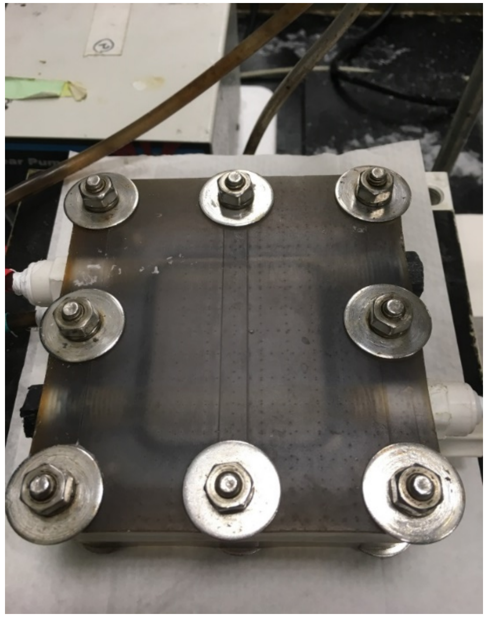
230 MW Coal Fired Power Plant

FGD Blowdown Concentration FO Testing



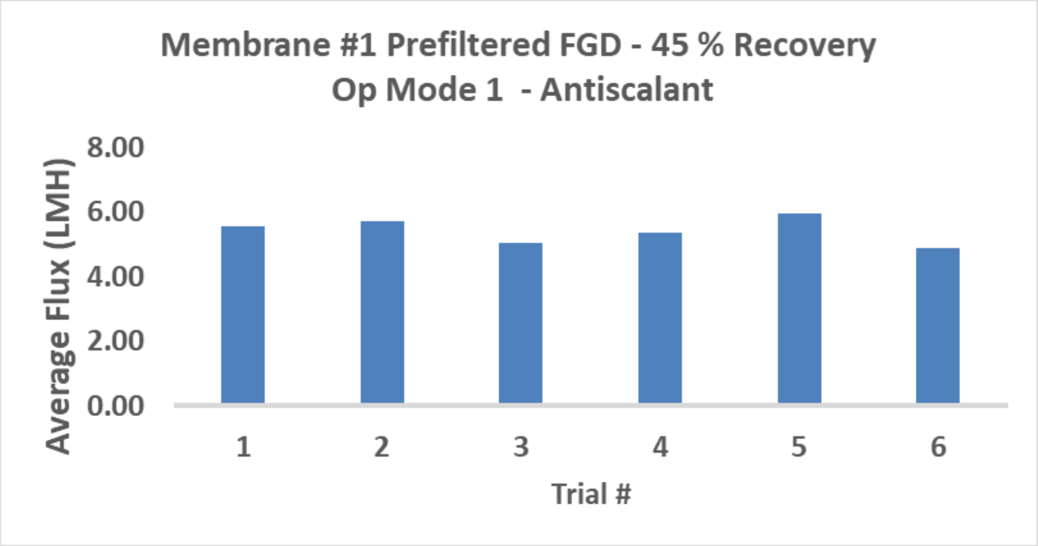
FO Batch Testing

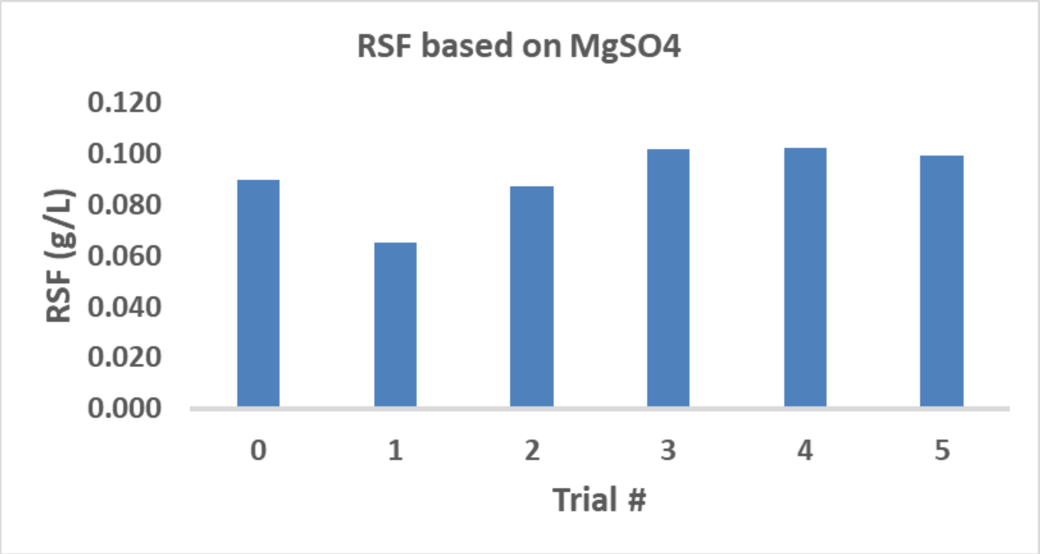




Membrane Cell
$0.00266\ m^2$

FGD Blowdown Concentration FO Membrane



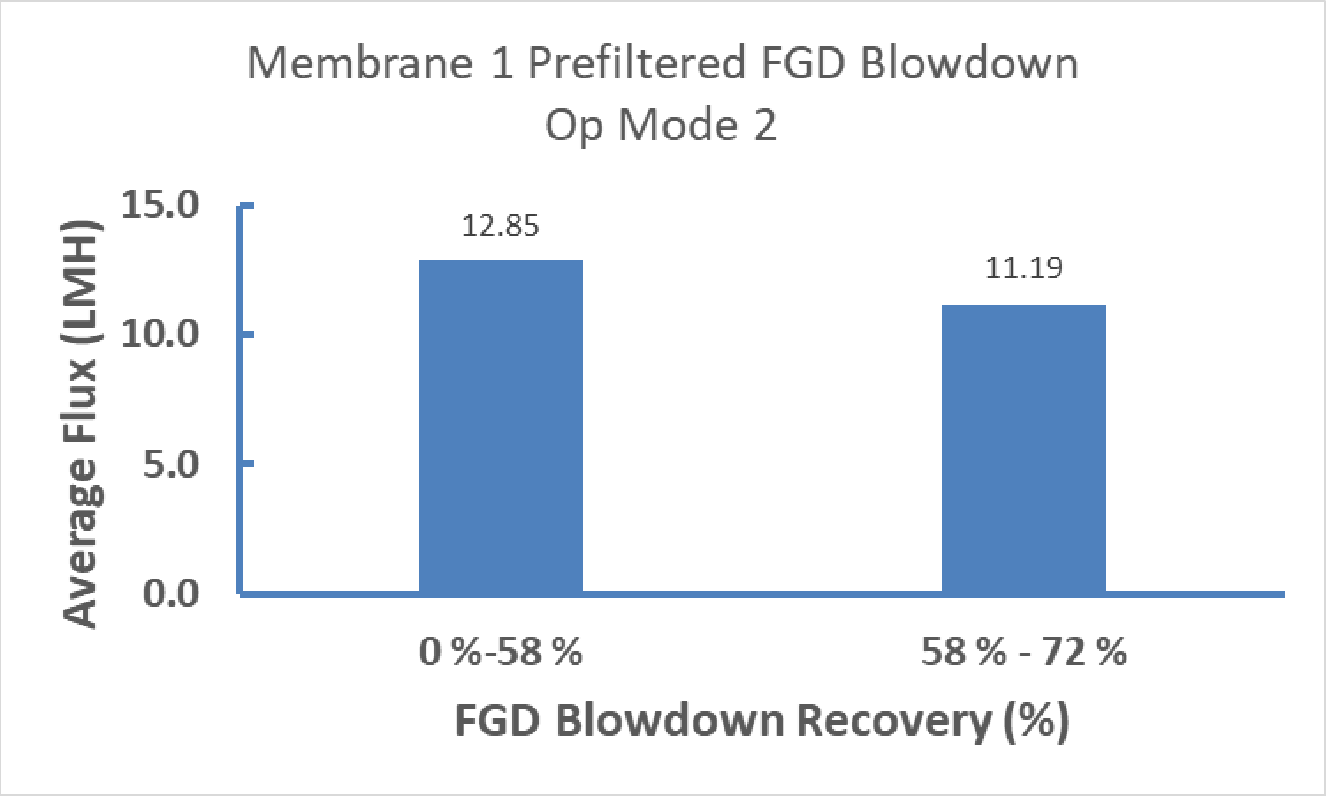


Membrane stable
RSF low
No precipitation of gypsum observed

Prefiltered 0.45 micron
Antiscalant addition ~4 ppm

FGD Blowdown Concentration FO Membrane

75% recovery achievable
Minimal pretreatment
No gypsum precipitation
Future work to target 90% recovery



Prefiltered 0.45 micron (gear pump requirement)
Process will use 2-5 micron filtration
Antiscalant addition ~4 ppm

Section 3

230 MW Coal Fired Power Plant

Aquapod – Working Principle

FGD-FO Data

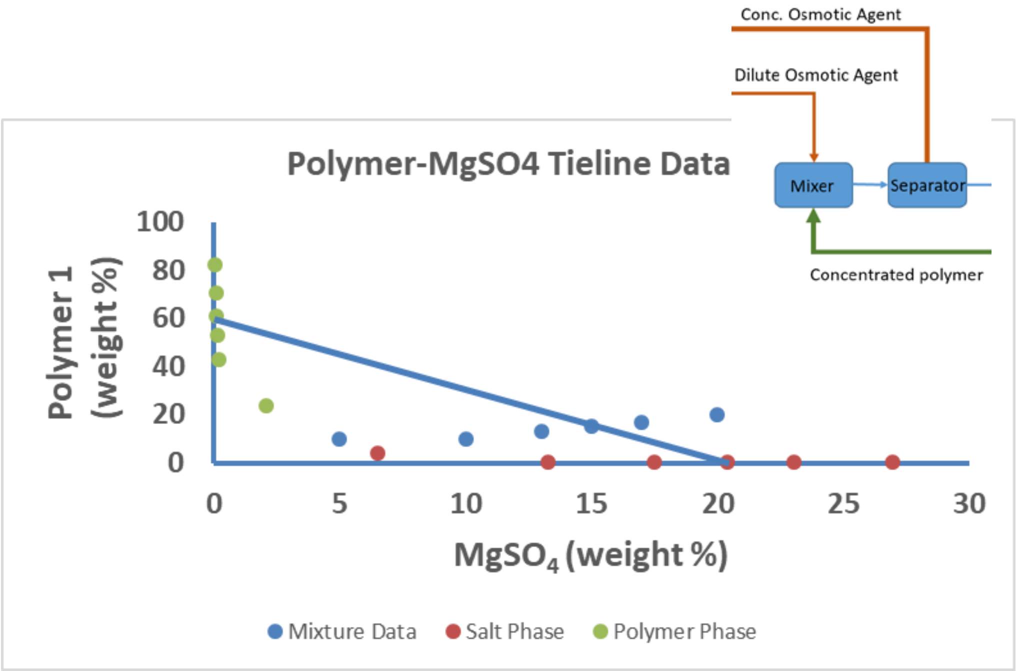
Salt-Polymer Selection Considerations

Summary

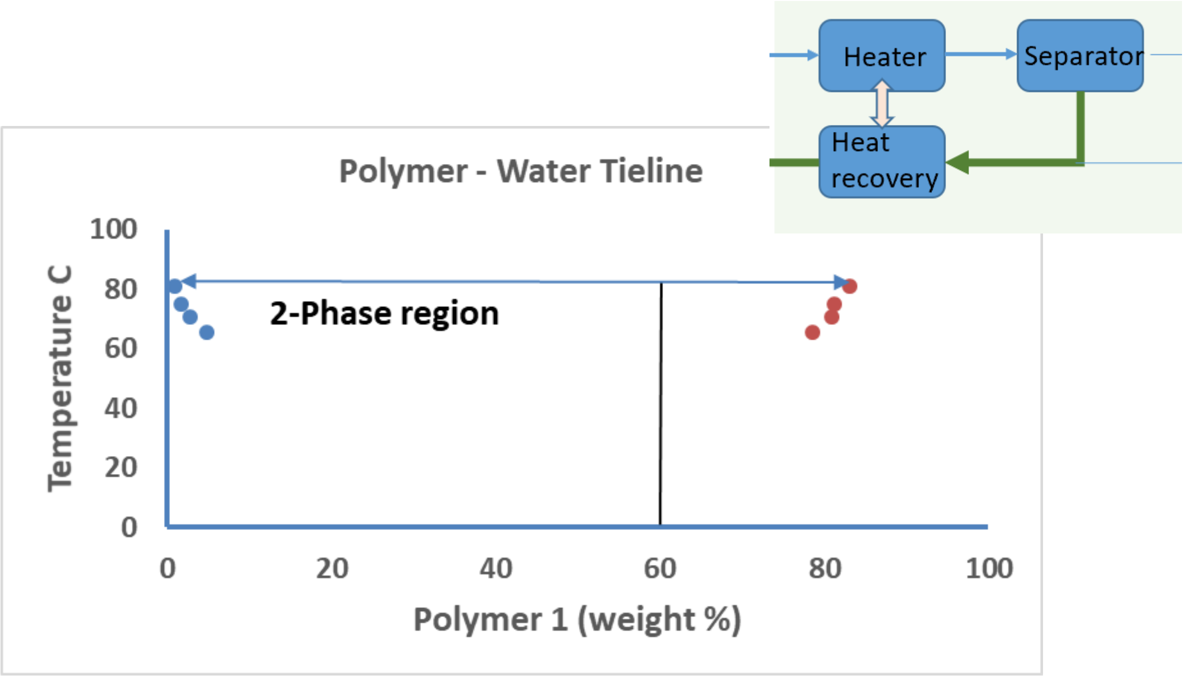
Next Steps

Polymer Selection Criteria

- Polymer ability to extract water from salt solution (MgSO4)
  - Required data - salt – polymer tieline data; polymer – water phase diagram as function of temperature - calculate g water extracted/g of polymer

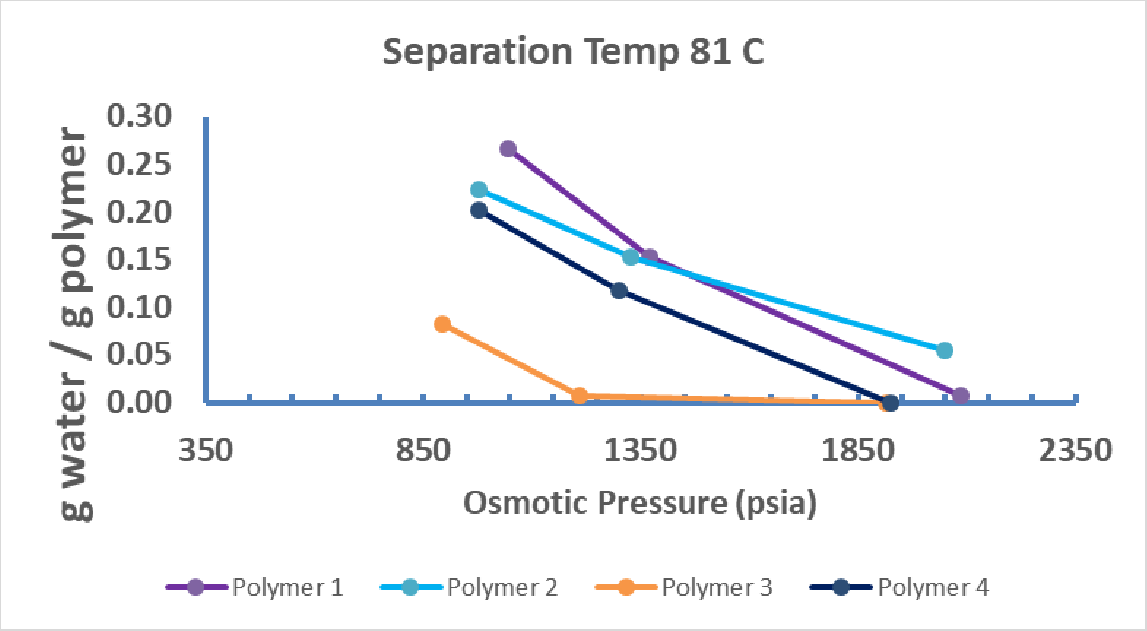


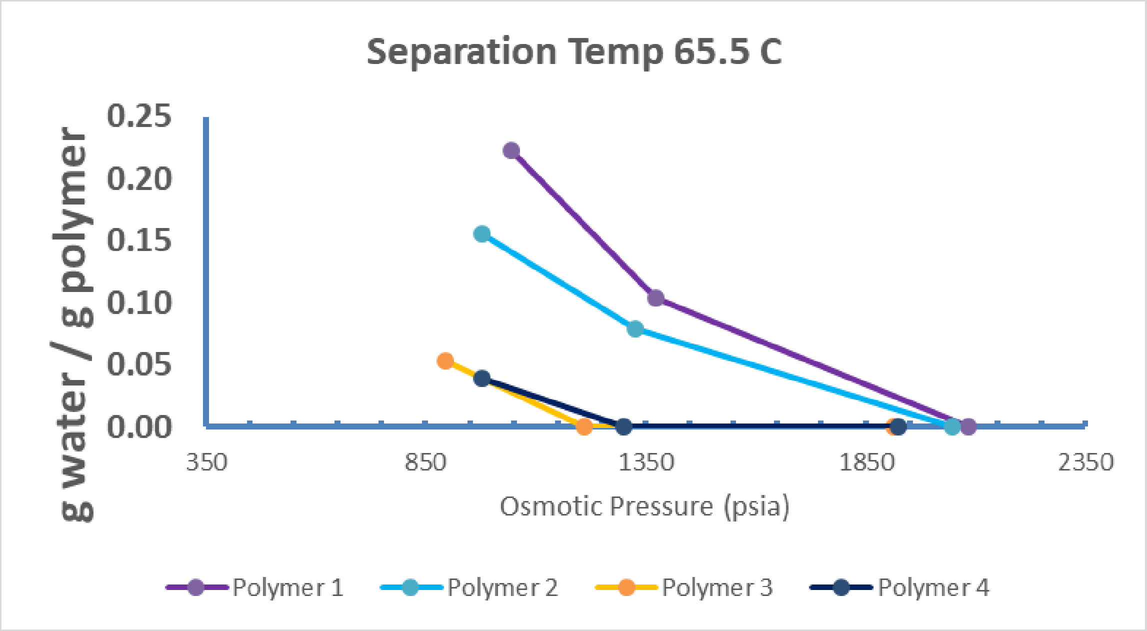
Step 2



Step 3

Water Extraction Capacity of Polymers





Polymer Selection Criteria

- Polymer – Salt separation kinetics
- Polymer – Water separation kinetics
- Polymer cost
- Polymer stability

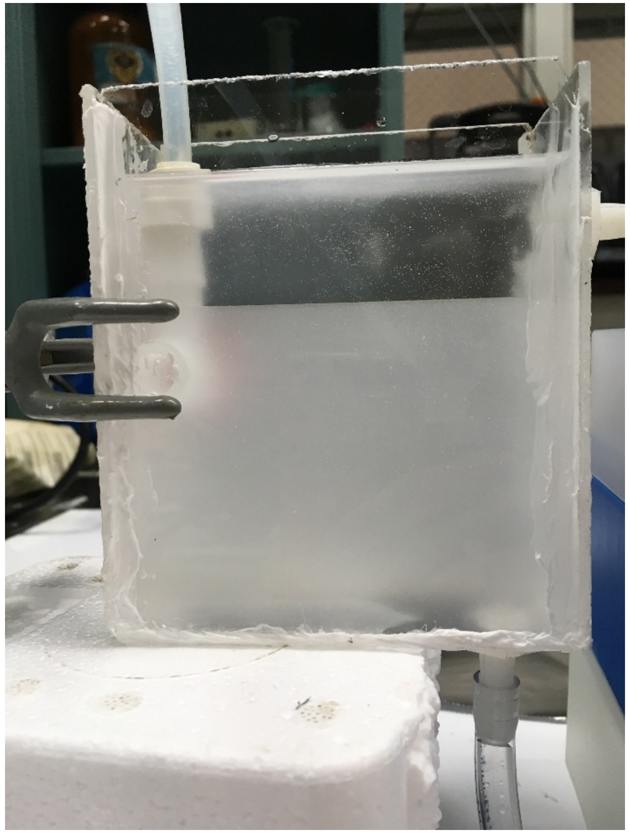
$MgSO_4$-Polymer Separation Kinetics

Impeller mixing of all polymers and salt achieves phase equilibrium in <2 minutes

UCON polymer phase separates cleanly in 30 minutes under gravity;

Salt phase hazy with particles of ~10 micron

Ongoing work to lower separation time and reduce carryover in bottom phase;



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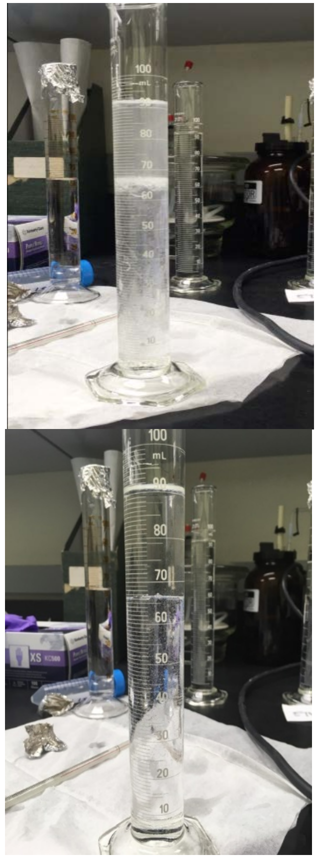
Polymer Water Separation Kinetics

- Polymer Water Separation ~84 C
  - Polymers 1 and 4 separate readily within 5 minutes for process relevant conditions
  - Polymer 2/3 more difficult
  - Further exploration in scale-up



Before

<5 min of settling

Polymer 1

Polymer 4

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Polymer Selection Criteria
Other Considerations

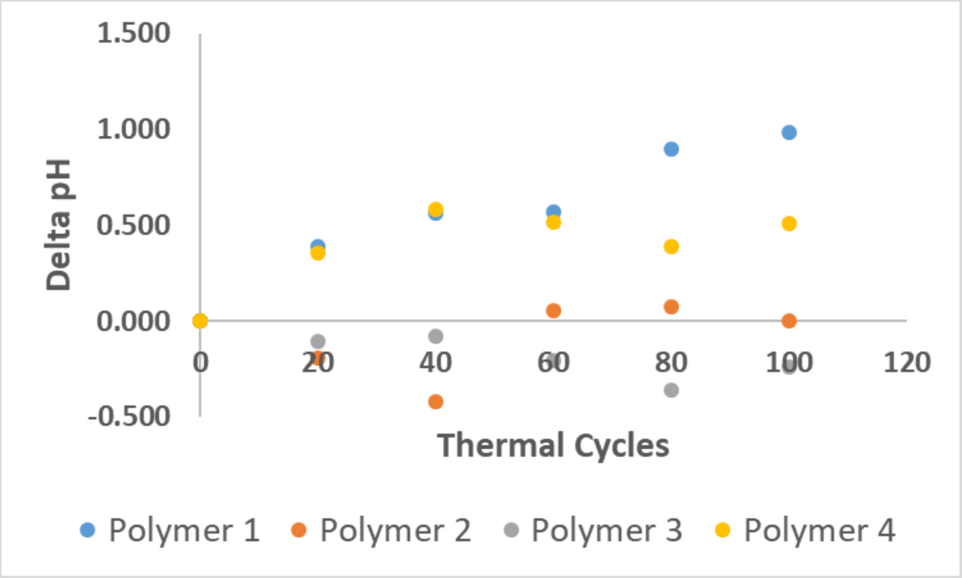
Cost

Polymer 1~Polymer 4

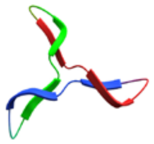
>

Polymer 2~Polymer 3

Thermal Stability



Polymers 1 & 4 show degradation indicating need for antioxidant stabilizers



$MgSO_4$ – Polymer Pairs

- Four $MgSO_4$ –polymer pairs identified
- All are able to provide osmotic pressures adequate for >80% recovery of water from FGD wastewater
- Three need a temperature of about 60 - 85 °C – accessible with flue gas;
- Polymer 3 has a low threshold temperature in the vicinity of condenser water temperature (45 ° C) – lower water carrying capacity/g polymer – intriguing possibilities for low TDS, high fouling streams
- Separations of salt-polymer and polymer-water do not seem to present unusual difficulty but will need to be optimized – may need coalescers etc.
- Polymer 1 will be used for scale-up; Polymer 4 is in commercial use; Polymer 2 is backup to polymer 1

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Summary

- Sufficient waste heat is available within power plant to recover significant amount of water from FGD blowdown using low energy FO.
- 50- 75% recovery water recovery from FGD blowdown has been achieved by FO at this plant **with minimal pretreatment** at small scale with coupons; achieved in short term tests. Next target is 90% recovery.
- Membrane flux is stable and viable at high recoveries;
- Energy target values of <200 kJ/kg and <2 kWh/m^3 achievable based on mass and energy balance, and preliminary PFD.

Next Steps

1. Conduct preliminary TEA and identify areas for improvement.

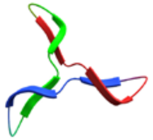
2. Integrate mixing and settling systems for salt-polymer separations.

3. Integrate heating and polymer-water separation units.

4. Test FO modules.

5. Identify residual management options.

6. Complete final TEA.



Notable Partnerships

- Working closely with FO membrane/equipment vendors, exchanging information, and best practices

- Working with IL Power Plant and leveraging their knowledge base on operation and treatment

Commercial partners and end-user involvement are critical to advance TRL of technology in subsequent scale-up

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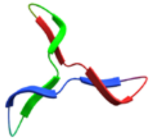

Acknowledgements

Project Team

- Mr. P. J. Becker (IL PP)
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- Mr. Brandon Powell (IL PP)
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THANK YOU