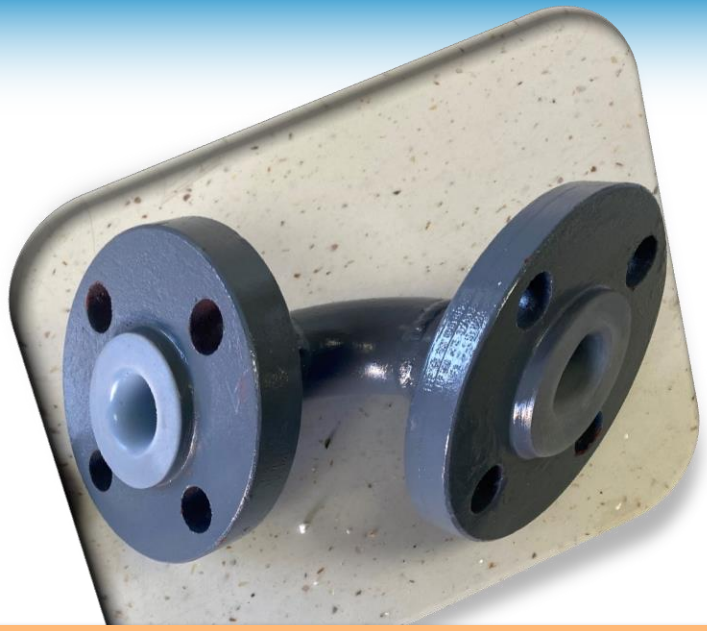

Hybrid Materials for Desalination Industries

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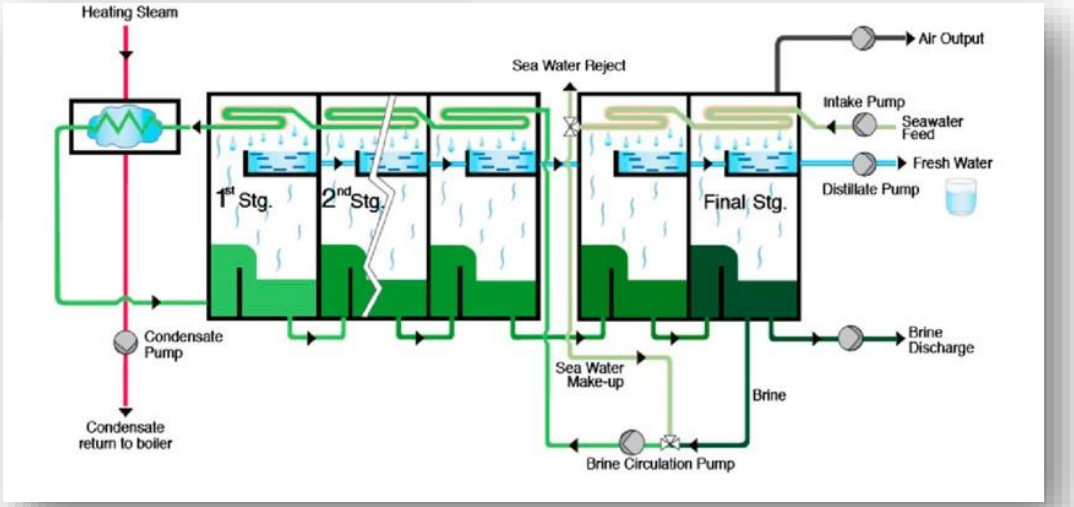
Topic

- Desalination processes
- Non-metal application in SWRO plants
- Non-metal application in MSF plants
- Non-metals in water transmission lines
- SWCC experiences of non-metallic materials
- Towards development of hybrid pipes
- Q & A

Desalination Processes

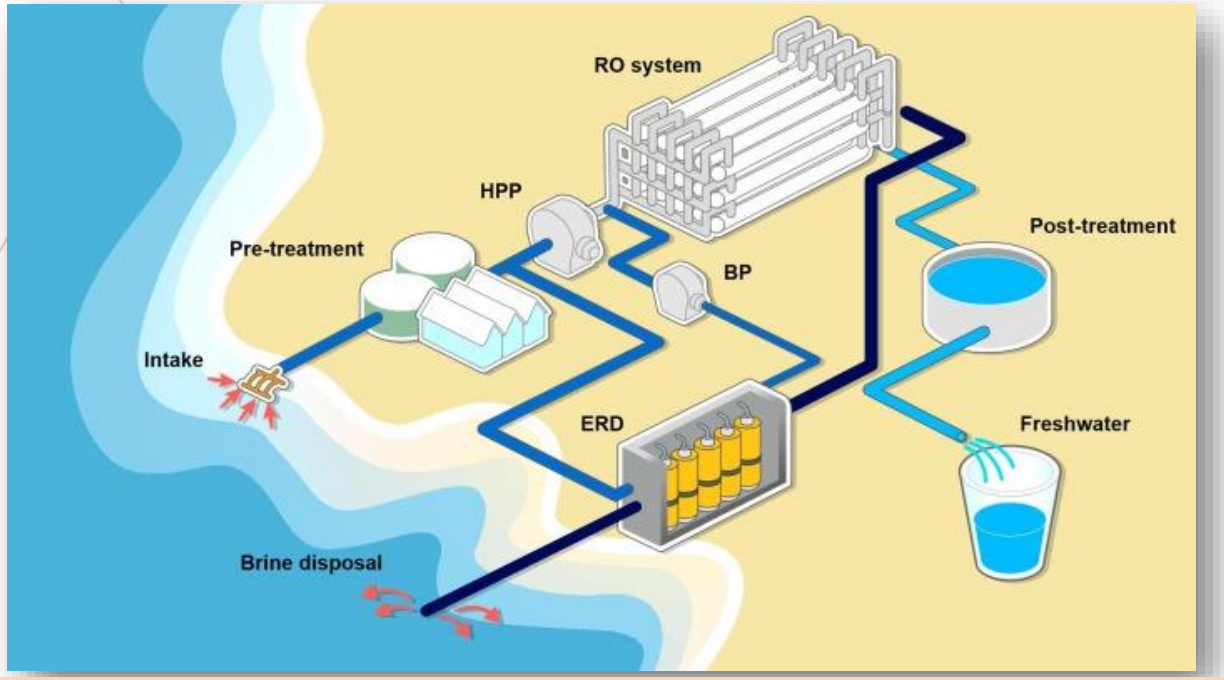
Thermal	**Multistage flash distillation (MSF)**	Saline water is heated and the pressure is lowered in several stages so the water flashes into steam, which is cooled.
	Multi-effect distillation (MED)	Low-pressure steam, 60 °C, is handled in a series of evaporative-condensers (effects) with heat rejection condensers.
	Mechanical vapor compression (MVC)	Distillation is affected by an electrically driven centrifugal compressor mounted on the evaporator.



Seawater Multi Stage Flash (MSF) system

Desalination Processes

Membrane	Reverse osmosis	Pressure is applied to the saline water, forcing it through a semipermeable plastic membrane that separates brine from water.



Seawater Reverse Osmosis (SWRO) main components

Membrane Process

Benefits and Challenges:

- **Relatively green process**: Due to environmental carbon footprint, membrane-based technologies became dominant for water industry specially Sea Water Reverse Osmosis (SWRO).
- **Application of non-metals:** The low-pressure (below 40 bar) section of the plant can utilize non-metallic materials e.g., fibre reinforced polymer (FRP).
- **Application of metals:** In high-pressure section, expensive corrosion resistant alloys (CRAs) are used due to the following qualities;
  - High corrosion resistance in brine water conditions
  - Structural integrity in a wide range of temperature and UV light conditions.
  - Ductility to avoid brittle fracture in case of operation pressure upsets/spikes.

Non-Metal Applications in SWCC RO Desalination Plants

Class	Material	Class Rating	Service
Thermoplastic	PVC	150#	Chlorine gas to gas scrubber
	CPVC	150#	Seawater, NaOCl
			HCl acid
			Chlorine solution
			Chlorine Gas
Composite (polymer matrix and glass fiber)	Glass reinforced plastics (GRP)	150#	Seawater Supply line to MSF
			Cooling Water Supply line to Power
			Seawater Supply line to RO
			Seawater Supply line to Seawater Chlorination, RO Analyzers
			Deaerator Feed Water Line, Cooling Water Recycle Line, CWRP Discharge, Seawater Discharge Line & to RO for Tempering
			Brine Recirculation Pump Discharge (Brine Bypass line up to isolation valve)
	GRP	150#	Desalination drainage, Aux Cooling Water Discharge, Potable water over flow line, Degasifier over flow line, BRP/BBDP Disc Isolation Valve Downstream, Water Box drain Header
	Glass reinforced Epoxy (GRE)	150#	Cooling Water Supply to Ma'aden
			Potable water Supply to Ma'aden
	Glass reinforced vinylester (GRV)	150#	NaOCl, HCl Acid, N_2 Purge / Waste water

Non-Metal Applications in SWCC MSF Desalination Plants

Class	Material	Class Rating	Service
Composite	GRP1R	150#	Seawater Supply Line
			DAF Treated Water + Air
			DAF Waste Sludge Water
			Back Wash Waste Water
	GRP2R	150#	1st Pass RO Train Outlet(Permeate)
			2nd Pass RO LP Pump Suction
	GRP3R	150#	2nd Pass RO Train Outlet(Permeate)
			Permeate Storage Tank Outlet
			Permeate Transfer Pump Discharge
			Flushing Header to 1st Pass RO HP Pump Suction
	GRP4R	150#	Backwash Waste Water Line
			Rinse Water Line Line
			Vent Line Line
			Drain Line
			DAF Treated Water
			Dual Media Filter Outlet
	GRP5R	150#	Filtered Water Pump Discharge
	GRE		Air Scour Line
	GRV	150#	NaOCl, HCL Acid, N2 Purge / Waste water
Thermoplastic	PVC	150#	DAF Spray Water (Indoor)
			1st & 2nd Pass Permeate J-Bend & manifold.
Thermoplastic	Polypropylene (PP)	150#	Ferric Chloride
			Sodium Hypochlorite

Non-Metal Applications in SWCC MSF Desalination Plants

Pumps:

- Reasonably high yield strength
- Low density
- High corrosion resistance
- Usually plastic pumps are cheaper than metal pumps
- Operating and maintenance costs are low
- Less noisy
- Operating temperatures range from 66ºC to 121ºC.

Non-Metal Applications in SWCC MSF Desalination Plants

Valves:

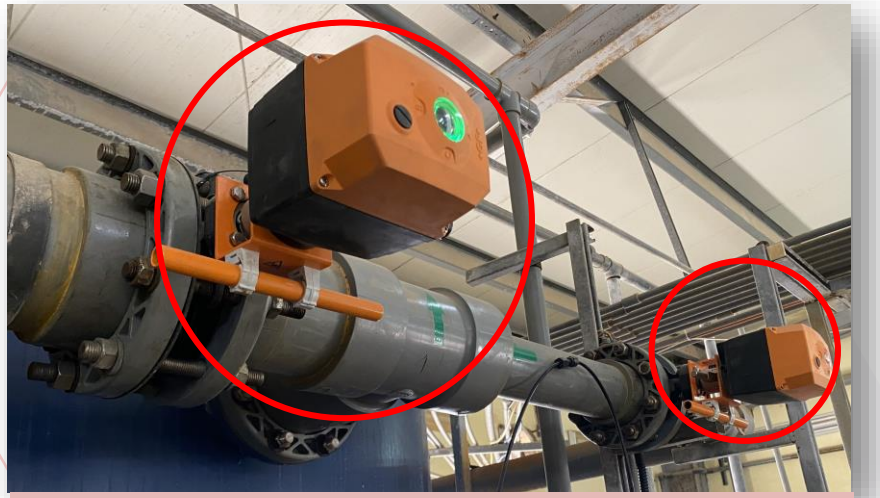
- The most common materials used for valve is Polyvinyl Chloride (PVC) which is thermoplastic polymer high in mechanical and chemical resistance
- The maximum working temperature can be reached to 60 ˚C.
- Other material type:
  - Chlorinated Polyvinyl Chloride (CPVC) with more rigidity properties and higher maximum working temperature up to 95 ˚C
  - Thermoplastic, thermoset & elastomers: Pigmented Polypropylene (PP), Polyvinylidene Fluoride (PVDF), FRP, GRP etc.

Non-Metal Applications in SWCC RO Desalination Plants

Valves:

- Metallic valves in the SWRO system experience corrosion both on internal and external sides.
- This adversely affects the efficiency, productivity and energy consumption of the plant.
- **Two plastic (PVDF) valves with actuators were selected to be tested in the pre-filtration section of the Pilot RO plant of WTIIRA.**
- Expected benefits;
  - Longer life due to better erosion and corrosion resistance of thermoplastic.
  - Lower maintenance cost and lightweight.
  - Connection with smart actuators , allows for automation and digitization.

Non-Metal Applications in SWCC RO Pilot Plant



Plastic butterfly valves 6” and 4” with actuators installed in WTIIRA Pilot Plant

- Location = SWCC RO Pilot plant
- Seawater inlet line = 4 inch GF valve 565 with motorized actuator
- Seawater back wash line = 6 inch GF valve 565 with motorized actuator
- TDS / Conductivity Level = 58500 - 61000 m/s
- Operating Pressure = 2.0 Bar - 3.5 Bar
- Operating Temperature = 18.0˚C - 43.0˚C
- Number of operation Cycle = 3 Cycle In 24 hours
- Date of installation = Jan 2023
- Performance = Running without failure

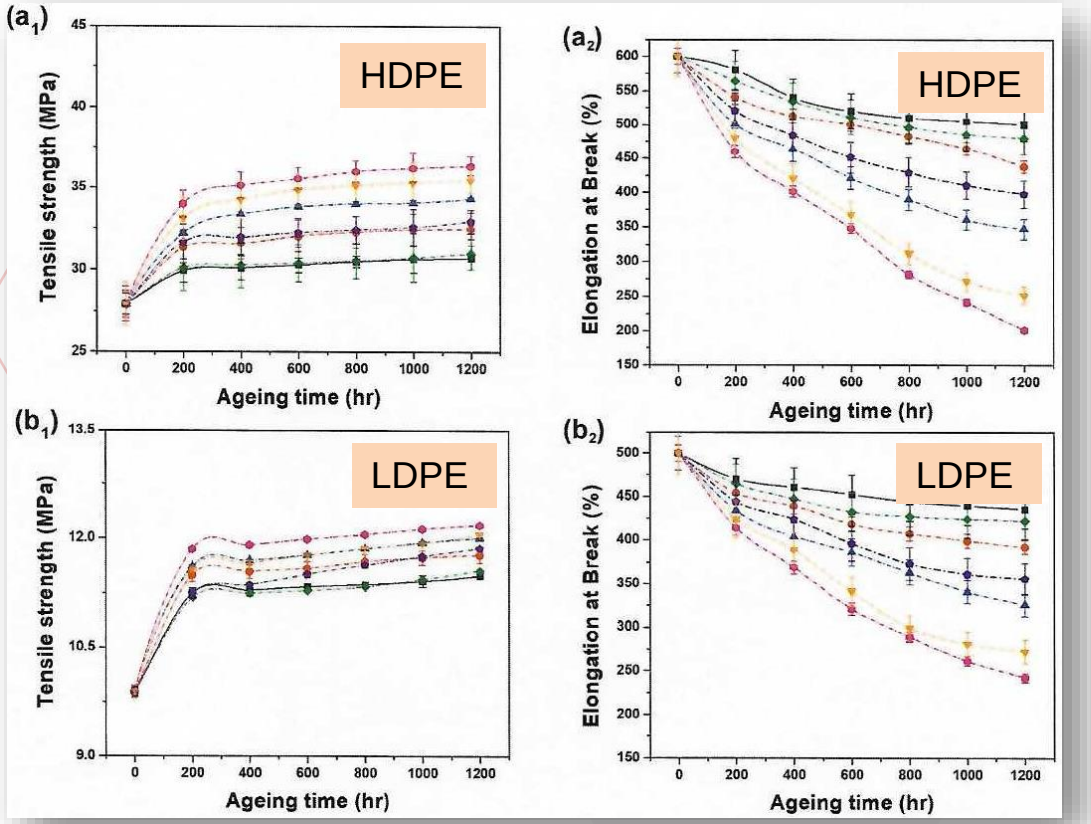
Non-Metals in Water Transmission Lines

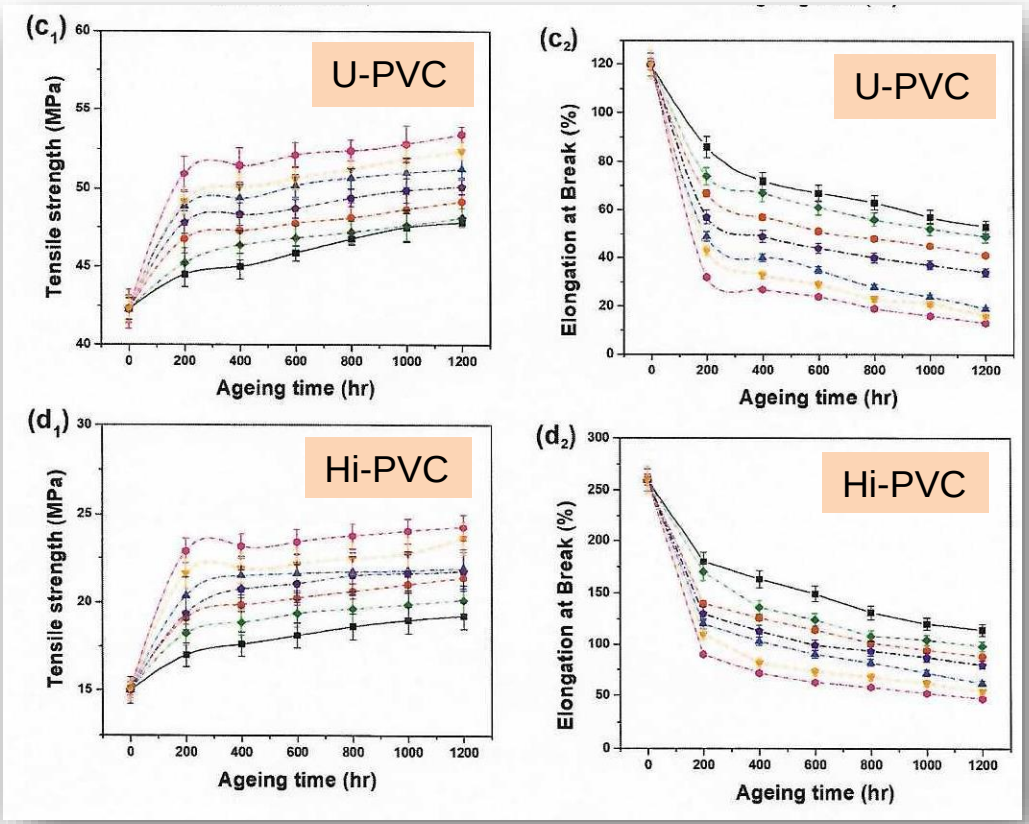
Pipes:

- Metallic and composite pipelines are the most economical means for transporting water, oil, and gas in various applications.
- *Limitations; Corrosion degrades metallic pipelines' strength capacity, while matrix cracking/abrasion causes leakage of composite pipelines.*
- Many researchers were interested in using FRP material to eliminate matrix cracking and decrease the possible corrosion. FRP layers are also being used to repair the existing conventional pipes.
- Polymeric pipes made of materials such as polyethylene (PE) and polyvinyl chloride (PVC) are also used for water transmission lines.
- *Limitations: Reactivity of ClO_2, a chlorine-based disinfectants, with polymeric materials can cause accelerated antioxidant consumption and polymer material embrittlement.*

Non-Metals in Water Transmission Lines

Pipes: **Polymeric pipes under chlorination doses, 1–10 ppm of ClO_2 and NaOCl, 40°C for 1200 h**





DI water; 2 mg/L ClO_2; 5 mg/L ClO_2; 10 mg/L ClO_2
2 mg/L NaOCl; 5 mg/L NaOCl; 10 mg/L NaOCl

Ref.: *I. A. Khan, K.H.Lee,Y. Lee, J. Kim, Degradation analysis of polymeric pipe materials used for water supply systems under various disinfectant conditions, Chemosphere, 291(2022), 13266.*

Non-Metals in Water Transmission Lines

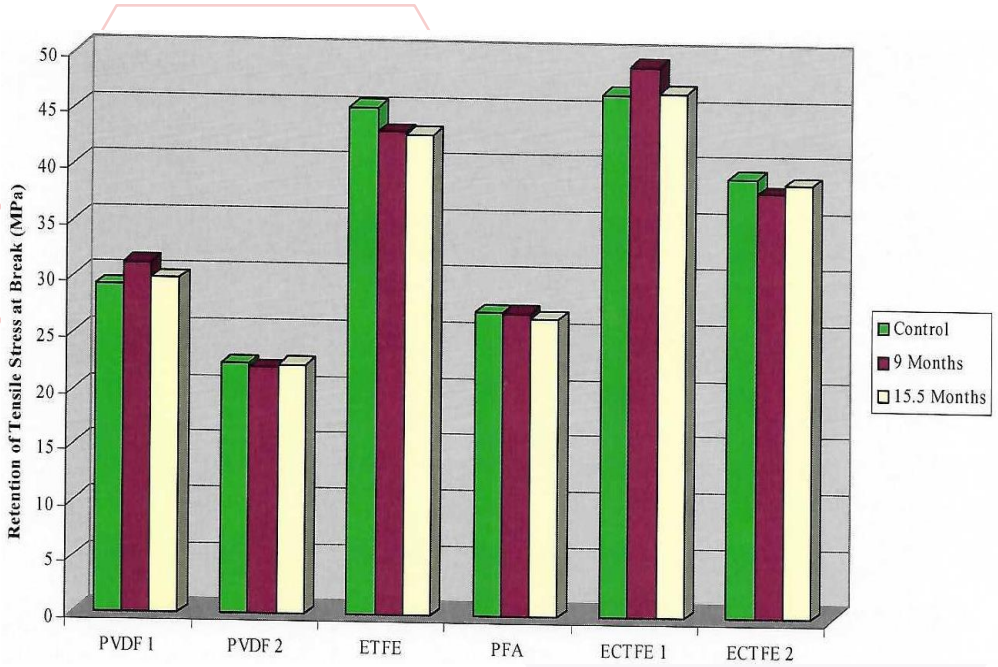
Pipes: **Polymeric pipes under chlorination doses, 1–10 ppm of ClO_2 and NaOCl, 40°C for 1200 h**

Findings:

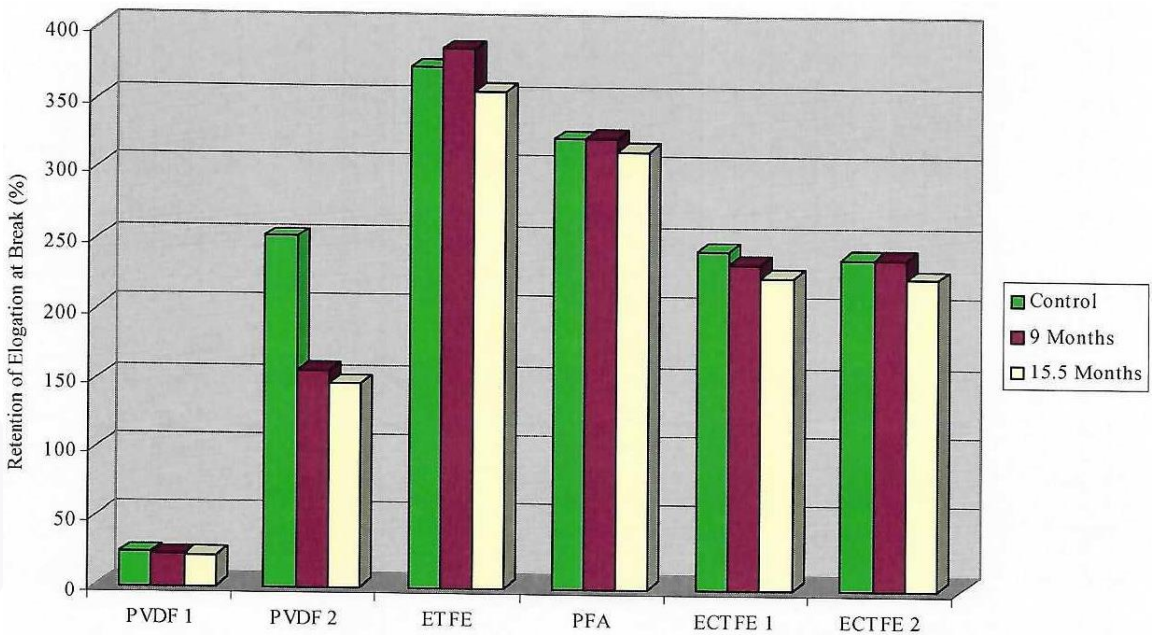
- Increase in tensile strength - Likely due to increases in the crystallinity and crosslinking density of the pipes under accelerated aging conditions.
- Oxidation of pipe materials led to chain alignment due to an increase in secondary intermolecular bonds. Thus, oxidation of the chains caused an increase in fragility of the pipes and reduction in ductility due to chain scission.
- The decreasing trend was more significant in ClO_2-exposed pipes at 10 mg/L as compared to NaOCl in the same conditions.

Non-Metals in Water Transmission Lines

Pipes: **Fluoropolymer coating for protection of FRPs from ClO_2**



Tensile stress at break after ClO_2 exposure to fluoropolymers



Elongation at break after ClO_2 exposure to fluoropolymers

Ref. *: L. M. Dobosz, J. K. Argasinski, and T. V. Tran, The effect of highly concentrated chlorine dioxide on physical properties of fluoropolymers, Paper # 08533, NACE CORROSION 2008.*

Non-Metals in Water Transmission Lines

Pipes: **Fluoropolymer coating for protection of FRPs from ClO_2**

Findings:

- Fluoropolymers have been recognized as highly corrosion resistant to many chemical compounds and they can be used as protective liners for FRP structures.
- However, factors to be considered are the permeation resistance of the resin, and temperature.
- The Swedish Corrosion & Metals Research Institute studied diffusion and permeation rates of ClO_2 through seven different types of fluoropolymers using their proprietary indicator technique. Diffusivity of chlorine dioxide significantly varies depending on the fluoropolymer type.
- Example; at 80°C the diffusion coefficient for ClO_2 in fluoropolymer ECTFE (copolymer of ethylene and CTFE) was about ten times lower than in PVDF (Polyvinylidene fluoride, a member of Teflon).

Non-Metal Applications in SWCC RO Pilot Plant

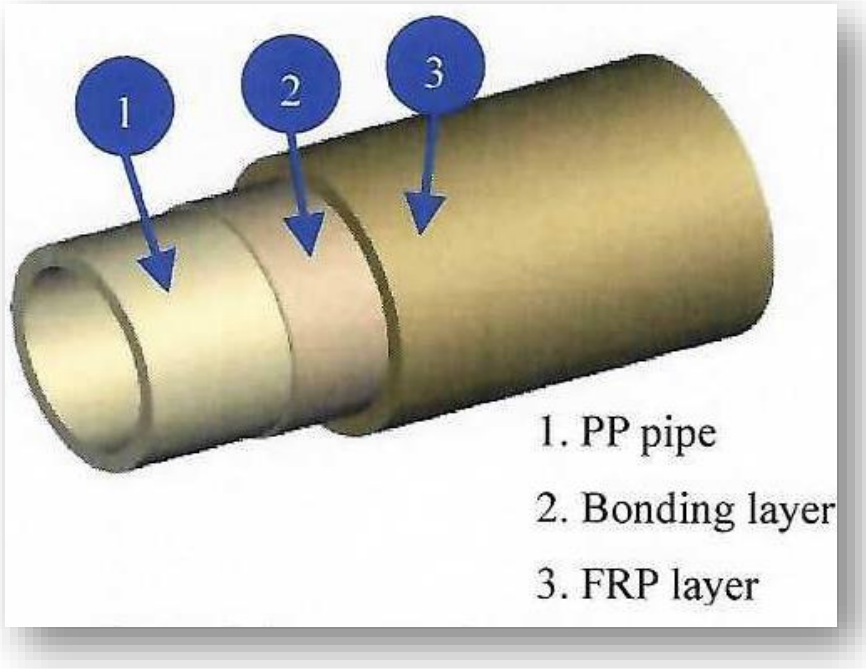
- In the reverse osmosis membrane system, the TDS of concentrated water discharged from the RO membrane is higher than that of sea water and the pressure is extremely high (above 60 Bar).
- Due to high strength and high corrosion resistance requirements, pipes and fittings of SWRO plants are usually constructed of super duplex stainless steel or super austenitic stainless steels. However, even in such super duplex pipes, corrosion is inevitable because of weld joints.
- ASAHI, a Japan company, worked on many pipes and valves made of resin typified by Poly Propylene (PP) and Poly Vinyl Chloride (PVC).
- In 2010, ASAHI developed high-pressure resin pipe (HPRP) while being corrosion-less.
- In 2016, SWCC/WTIIRA, Jubail, conducted a performance evaluation test of HPRP in their pilot plant.

Non-Metal Applications in SWCC RO Pilot Plant

HPRP (High Pressure Resin Pipe) is a developed using PP pipe as the inner layer and FRP lining on the outer layer, thereby achieving both corrosion resistance and high durability.

Features:

1. High corrosion resistance
2. Lightweight compared to metal
3. It can be made into any shape



Non-Metal Applications in SWCC RO Pilot Plant

HPRP test at Pilot Plant of SWCC.

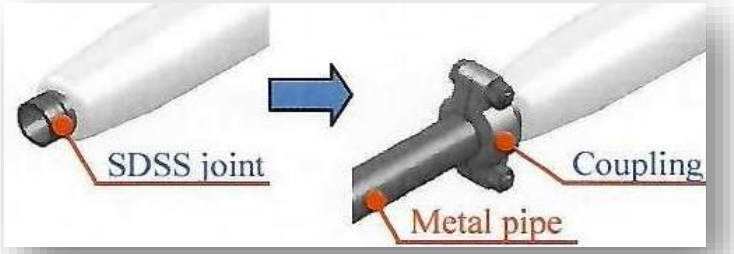
- Installed in ERD, which includes piping from the outlet of the RO membrane to the inlet. This section has highest pressure and TDS.
- Test conditions:
  - Capacity: 450m3/d
  - Recovery: 55%
  - Feed Pressure: 70-90 bar
  - SW TDS: 45,500mg/L

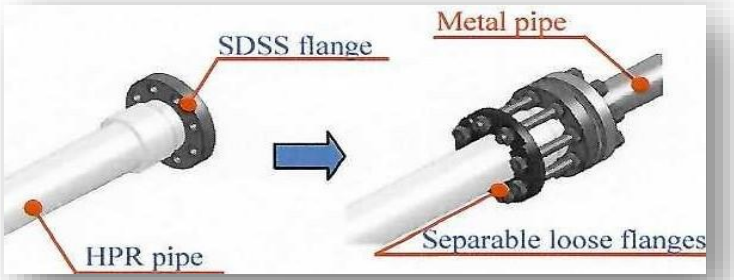
- Installed ASAHI Pipe qualities:
  - Pipe size: 1 1/2”-2 1/2”
  - Item: Pipe
  - Fittings & Joint Portion: RO to ERD path
  - Test period: 1 year

Non-Metal Applications in SWCC RO Pilot Plant

HPRP Test at Pilot Plant of SWCC.

HPRP pipe installed in RO Plant for 80 bar pressure, 1 yr.





Coupling and flange joints of HPRP

Non-Metal Applications in SWCC RO Pilot Plant

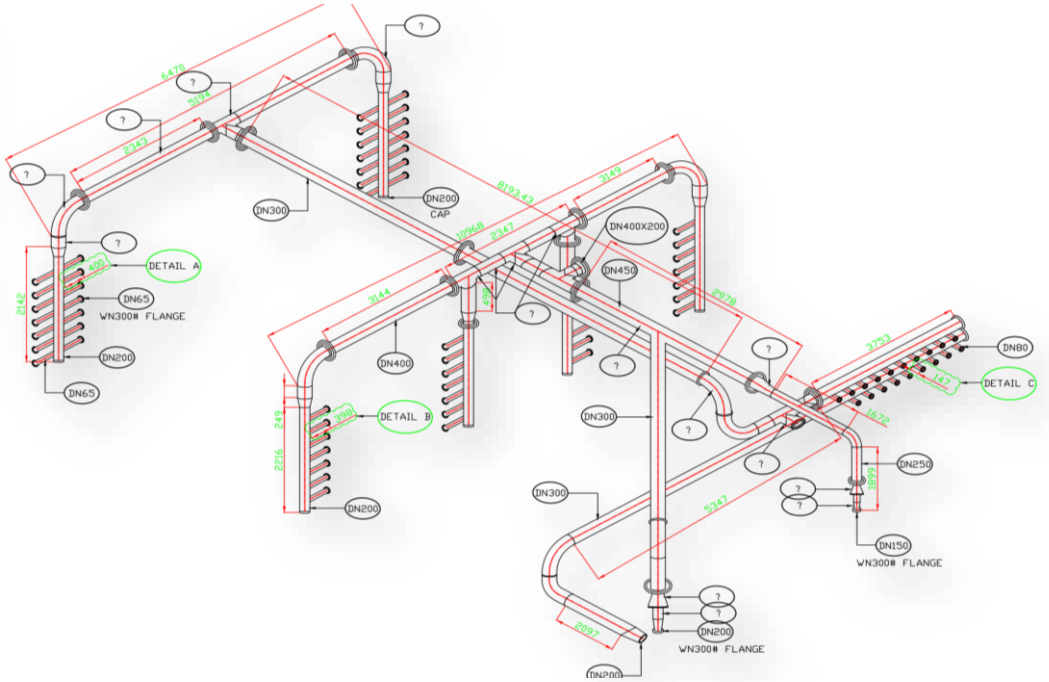
Hybrid Pipe Development and Test at Pilot Plant of SWCC

- Super duplex stainless steels (SDSS) are used for high pressure transmission lines of RO plants.
- SDSS are very expensive, and they do corrode in marine atmospheric conditions and at weld joints.
- WTIIRA is working on development of polymer lined carbon steel pipes, where polymer will provide corrosion resistance against seawater and carbon steel pipe will take care of the high pressures (above 80 bar).
- Hybrid pipes will provide corrosion control, cost reduction and increase in service life of high-pressure water transmission pipelines of RO plants.

Non-Metal Applications in SWCC RO Pilot Plant

Hybrid Pipe Test at Pilot Plant of SWCC (in progress)

Hybrid spool under test in DTRI pilot plant at 70 Bar pressure



USTS Drawing of portable RO plant at Ras AlKhair with Hybrid Pipelines

Concluding Remarks

- Presently low-pressure sections of SWRO plants are using non-metallic materials e.g., fibre reinforced polymer (FRP). However, in high-pressure sections, CRAs are used.
- To make the SWRO technology cost effective and more efficient, research & development of high strength non-metals are very much needed to manufacture high pressure resistant pumps, pipes, valves etc.
- SWCC has performed a successful pilot plant test of application of high-pressure resin pipe (HPRP) at 80 Bar pressure, plastic valves, hybrid pipes for water transmission lines.
- Development of large diameter pipes and valves of high strength non-metals is the future research plan of WTIIRA. This type of material can find considerable application in desalination industries due to its high corrosion resistance and low installation costs.

Acknowledgement

WTIIRA research team is thankful to the SWCC management for their cooperation and support