AXIAL PISTON-PRESSURE EXCHANGER DEVELOPMENT PROGRAM

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1.0 Abstract

Through a contract with the United States Office of Naval Research (ONR), Ocean Pacific Technologies (OPT) is developing and testing new energy recovery and pumping technologies aimed at improving the efficiency of small and medium sized SWRO systems. OPT has developed a new hybrid design termed an axial piston-pressure exchanger (APX) pump. The APX is a combination axial piston pump (APP) and pressure exchanger (PX) machine. Axial piston pumps and pressure exchangers both use an axial piston design in which a cylindrical rotor/drum with longitudinal ducts/bores, rotates around a central axis. The new APX design capitalizes on these similarities to create a high efficiency pump and isobaric energy recovery device in a single machine that eliminates the need for extraneous booster pumps, flow controls and other auxiliary equipment.

A major benefit to the APX design lies in its potential to be applied to the full scale systems on the order of 0.1-1 mgd (400-3800 m3/day). Typically, these systems consume significantly more power than smaller systems because the main HP pump flows are too large for traditional positive displacement, high-efficiency plunger pumps to be practically applied. In these cases, centrifugal pumps with efficiencies of only 65-80% are typically used. The result is that these systems consume approximately 20-25% more energy than their smaller counter parts. But, because of the water hydraulic rotary design of the APX, this technology can provide a smooth flow, low maintenance and high efficiency solution.

This paper will present detailed descriptions of this new technology and development program. A detailed analysis of the technologies benefits and drawbacks will also be provided. In addition, operational data from alpha prototypes will be published.

2.0 OPT-ONR CONTRACT BACKGROUND

As part of the ONR's Expeditionary Unit Water Purifier (EUWP) science and technology program, OPT was awarded a contract in December 2005 to develop pump and energy recovery technology for very small seawater reverse osmosis (SWRO) systems on the order of 200-20,000 gpd (0.7-75 m3/day). In the base portion of the contract, several energy recovery approaches were initially identified and modeled before selecting two approaches to pursue and prototype. The first approach included testing the axial piston pump and axial piston motor (APP-APM) technology. This approach has proven to be very suitable for small scale systems and is now being implemented at the commercial level. In addition, the army plans to fund field testing of this technology into their 1800 gpd (6.8 m3/day) Light Weight Water Purification system. The second approach of this program was to develop a completely new hybrid concept termed the axial piston-pressure exchanger (APX). The result of the work on this second approach has shown that it could offer significant benefits to larger scale systems if this technology can be scaled up.

The APX is new kind of combination APP and PX hybrid machine. Axial piston pumps and pressure exchangers both use an axial piston design, where a cylindrical rotor/cylinder with longitudinal ducts/bores rotates around a central axis. The cylinder barrel and bores are similar to an old-style gatling machine gun or revolver hand gun. In the APP, pistons inside the bores ride against a swash plate that creates the oscillating/pumping motion. APP's have been applied in oil hydraulic systems for decades, but there have recently been good technological advancements in the field of water hydraulics, in which water is used as a lubricating and hydraulic fluid instead of oil. In the PX, RO reject water is used to directly pressurize new incoming seawater within each axial aligned bore. The similarities in design and application of APP and PX technology have led OPT to develop an APX hybrid pump.

3.0 Axial Piston Pump-Pressure Exchanger Hybrid Approach

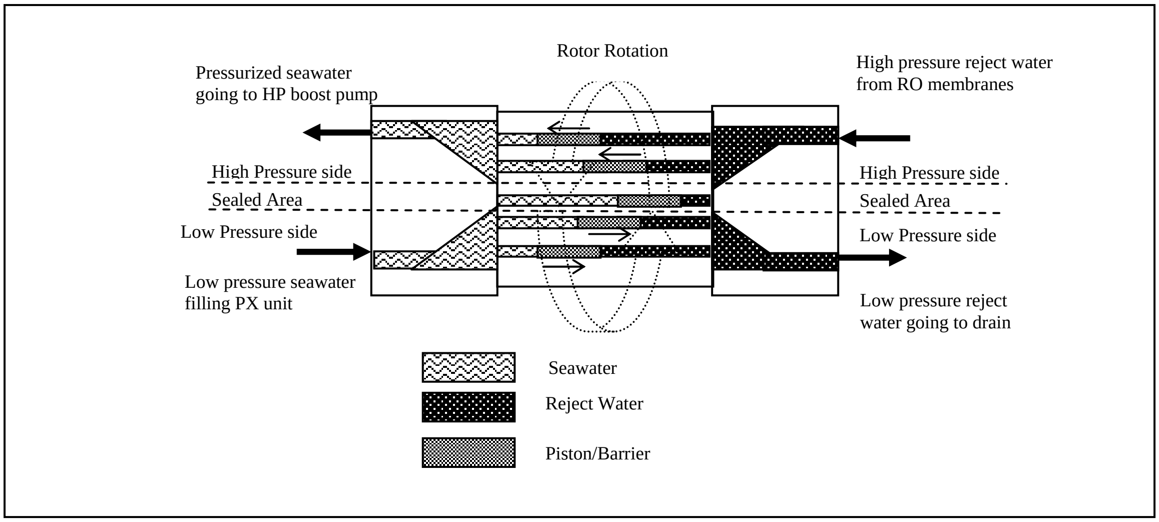
Pressure exchangers have proven to be highly efficient simple devices that yield the lowest possible energy consumptions on the order of 7.5 kWh/kgal (2 kWh/m3)[1]. However, due to their system complexity and overall high cost they have not been widely applied to RO reject flows under 20 gpm (4.5 m3/hr) or SWRO systems smaller than approximately 20,000 gpd (75 m3/day).

A pressure exchanger utilizes the principle of positive displacement to allow low-pressure filtered and/or treated seawater to be pressurized by direct contact with the concentrated brine stream from a seawater reverse osmosis system. The device uses a cylindrical rotor with axial aligned ducts to transfer the pressure energy from the concentrate/reject stream to the feed stream. The rotor spins inside a sleeve between two end covers with port openings for low and high pressure. The low-pressure side of the rotor fills with seawater and the high-pressure side discharges seawater.

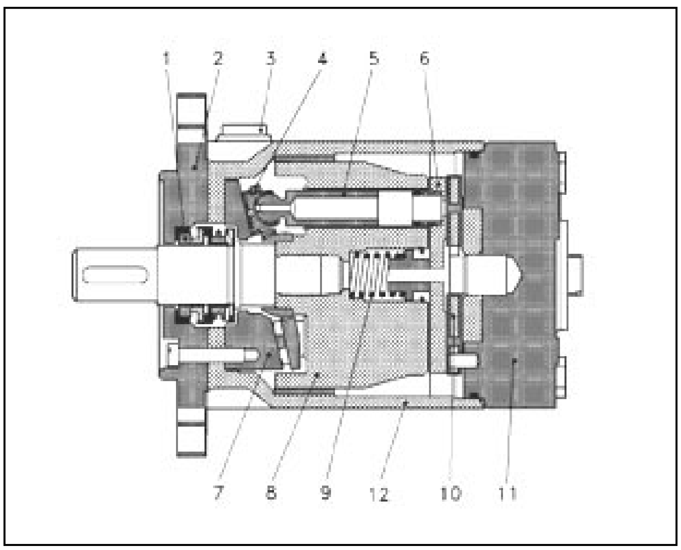
By rotation the ducts are exposed to the low pressure feed water, which fills the duct and displaces the reject water. The rotor continues to rotate and is exposed to the high-pressure concentrate, which fills the duct and displaces the feed water at high pressure. The ducts continuously fill and discharge with the rotation of the rotor. See Figure 1 for a diagram of a pressure exchanger unit.

[1] MacHarg, J. 2001. Exchanger Tests Verify 2.0 kWhr/m3 SWRO Energy Use. International Desalination and Water Reuse Quarterly. 11:1

Figure 1. Pressure Exchanger Diagram



APP pump design is similar to a pressure exchanger in that they both incorporate a cylindrical rotor with axial aligned ducts. In the APP, pistons inside the ducts ride against a swash plate that creates the oscillating/pumping motion. Figure 2 shows a typical APP design.

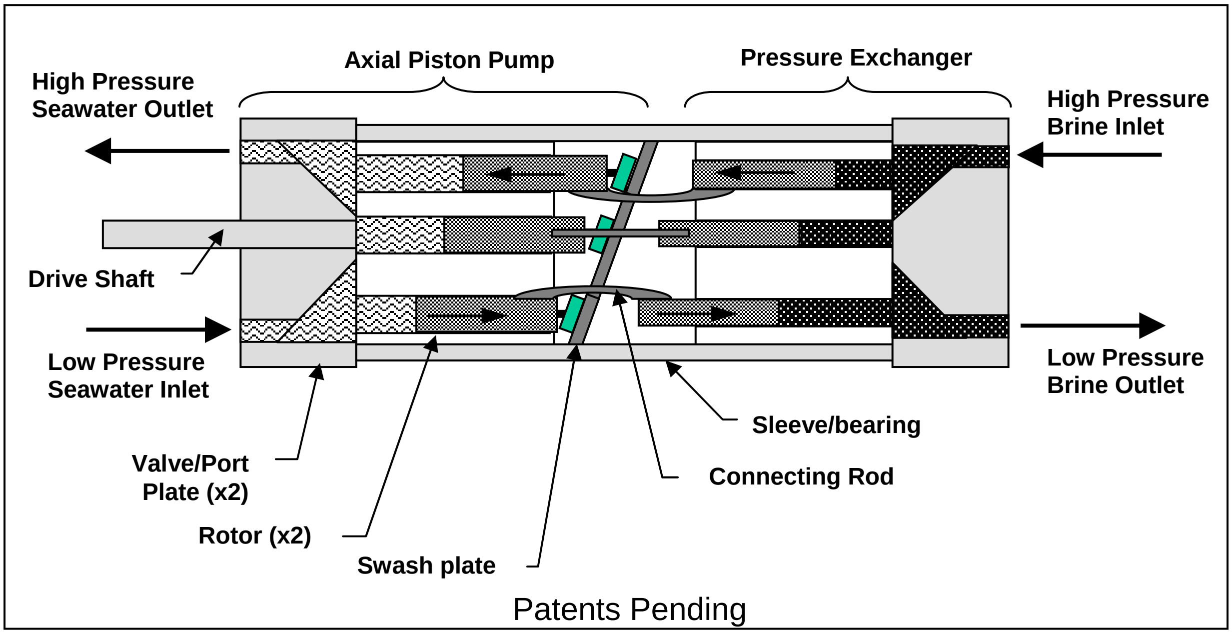


1. Shaft sealing
2. Mounting flange
3. Bleeding plugs
4. Retaining ring
5. Piston/shoe
6. Valve/trust plate
7. Swash plate
8. Cylinder barrel
9. Spring
10. Port plate
11. Connecting flange
12. Housing with bearing

Figure 2. Axial Piston Pump/Motor

The axial piston rotary approach of the pressure exchanger is remarkably similar to the rotary design of an APP. The high efficiency of the PX and its similarities to the APP have led OPT to develop the APX hybrid pump design as shown in Figure 3.

Figure 3. Axial Piston Pump – Pressure Exchanger Hybrid



A simple flow diagram and power model of the APX system are shown in Figures 4 and Table 1.

Figure 4. APX System Diagram

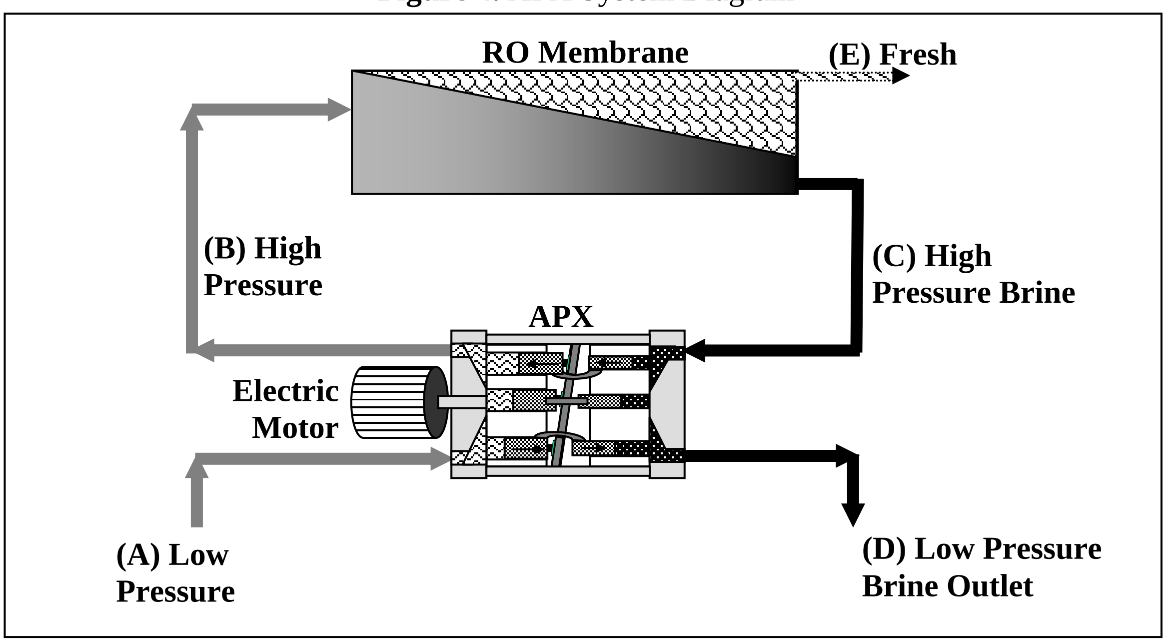


Table 1. APX Flow and Pressure Power Model

		A	B	C	D	E
FLOW	gpm	100.0	100.0	60.0	60.0	**40.00**
	gpd	144,000	144,000	86,400	86,400	57,600
	l/min	378	378	227	227	151
	m3/day	545	545	327	327	218
PRESSURE	psi	**20**	**850**	830	5	5
	bar	1.4	58.6	57.2	0.3	0.3
QUALITY		SEA	SEA	BRINE	BRINE	PERMEATE

APX Parameters

Net Transfer Efficiency	%	**94%**

RO Membrane Parameters

Membrane Differential	PSI	**20**
Recovery	%	**40%**

APP High Pressure Pump Power

Feed Pump eff	%	**90%**
Motor efficiency	%	**93%**
Power	kW	19.86

Savings

% Power savings	55%

Total Power Consumption

Total RO Process (kW)	19.86
kWh/1000 gal Permeate	8.3
kWh/m3 permeate	2.19

Table 1 shows the projected flow, pressure and power parameters for a 100 gpm (23 m3/hr) APX feed system operating at 850 psi (59 bar) and 40% recovery, producing 40 gpm (9 m3/hr) of permeate. The APP pump side of this APX unit produces 100 (23 m3/hr) gpm at 850 psi (59 bar) while the smaller diameter pistons of the PX side of the APX unit can only accept 60 gpm (14 m3/hr). The remaining 40 gpm (9 m3/hr) permeates through the RO membranes and becomes product water.

Some of the benefits of the APX pump system are as follows:

- Reduced power consumption over the APP-APM approach
- Significantly fewer moving parts than the APP-APM system
- Simpler application compared to the isobaric systems (ie. fixed flows and no booster pump)
- No mixing between the brine and feed streams compared to other isobaric systems
- Smooth flow - high efficiency rotary piston design
- Ultra-low maintenance water hydraulic design
- Fixed RO recovery simplifies control requirements (see negatives)

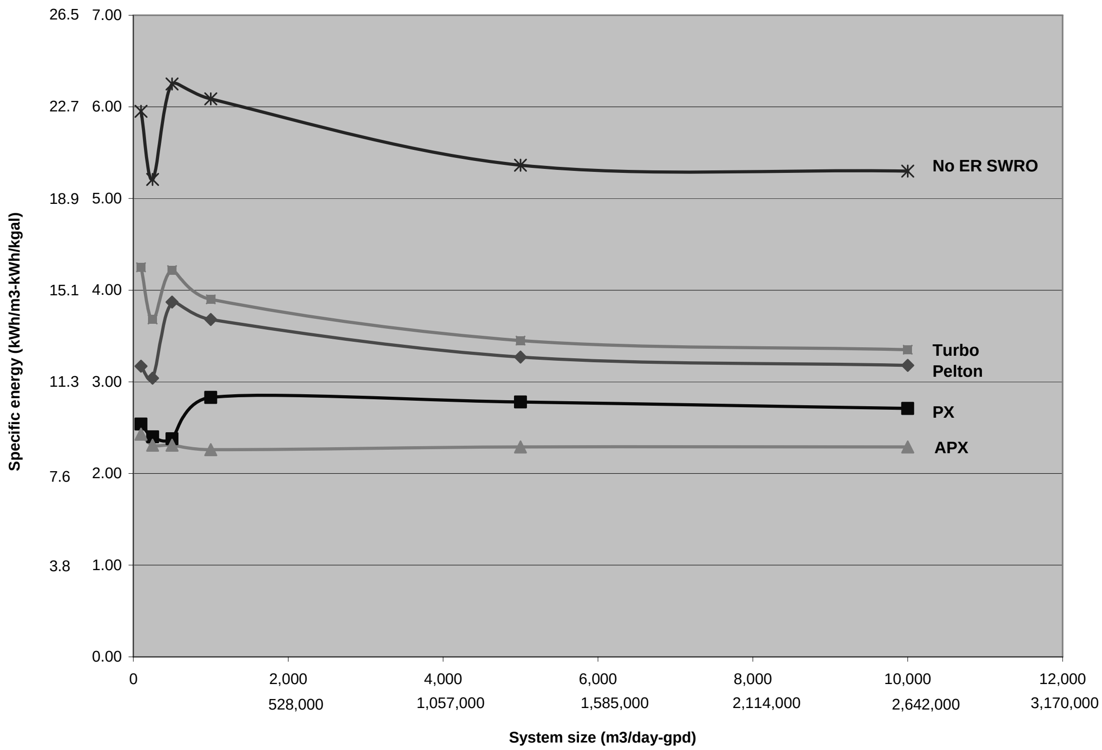
Negatives of the APX system might include:

- Multiplicity of moving parts compared to some isobaric-centrifugal combination systems
- Fixed RO recovery limits operational flexibility (see positives)
- Lack of commercial experience

Another major benefit to the APX design lies in its potential to be scaled up to the full scale systems on the order of 0.1-1 mgd (400-3,800 m3/day). Typically, these systems consume significantly more power than smaller systems because the main HP pump flows are too large for traditional positive displacement, high-efficiency plunger pumps to be practically applied. In these cases, centrifugal pumps with efficiencies of only 65-80% are applied to the full scale systems/trains between 0.1-1 mgd (400-

3,800 m3/day). The result is that these systems/trains consume approximately 20-25% more energy than their smaller counter parts. But, because of the water hydraulic rotary design of the APX it is likely that this technology can be scaled up to provide a smooth flow, low maintenance and high efficiency solution. Figure 5 shows how an APX pump could reduce the power consumption for these larger full scale SWRO systems compared to traditional energy recovery (ER) and pumping technologies.

Figure 5. Relative Power Consumption of Various ER systems and the APX[2]



3.1 APX Progress

OPT's initial approach to prototyping the APX concept has been to build on and move out from the Danfoss APP 1.0 pump, which has a maximum flow capacity of approximately 5 gpm (1.1 m3/hr). The APP side of the APX hybrid is essentially an APP 1.0 with minor modifications and the PX side of the APX is an APP 1.0 with smaller diameter pistons and the swash plate removed. Connecting rods from the energy recovery PX pistons to the APP pistons are integrated into the assembly. See figure 6 below for a virtual model of the concept.

[2] Projection system and efficiency assumptions: 100 m3/day, 62 bar feed pressure, 35% recovery, 90% eff. HP pump, 50% eff. PX booster, 45% nte turbo, 80% eff. Pelton; 250 m3/day, 62 bar feed pressure, 40% recovery, 90% eff HP pump, 55% eff PX booster, 50% nte turbo, 85% eff. Pelton; 500 m3/day, 62 bar feed pressure, 40% recovery, 90% eff PX HP pump, 60% eff PX booster, 75% eff tubo/Pelton HP pump, 55% eff. turbo, 85% eff Pelton; 1000 m3/day, 62 bar feed pressure, 40% recovery, 74% eff PX HP pump, 65% eff PX booster, 77% nte turbo/pelton HP pump, 61% nte turbo, 86% eff Pelton; 5000 m3/day, 66 bar feed pressure, 45% recovery, 78% eff PX HP pump, 78% eff PX booster, 82% nte turbo/Pelton HP pump, 66% nte turbo, 87% eff Pelton; 10,000 m3/day, 66 bar feed pressure, 45% recovery, 80% eff PX HP pump, 80% eff PX booster, 68% nte turbo, 88% eff Pelton; PX, turbo and Pelton projections generated with ERI power model rev. 8/25/05.

Figure 6. APX Hybrid Virtual Model

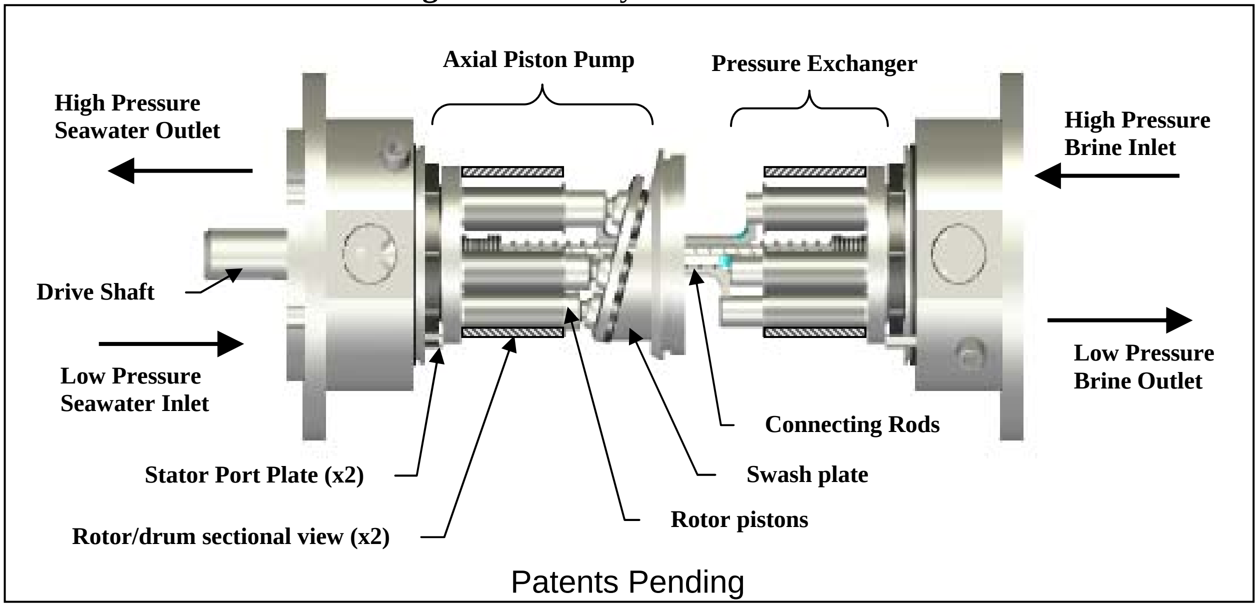


Figure 7 shows a picture of a 5 gpm (1.1 m3/hr) prototype. Bench testing of this prototype is ongoing and thus far has yielded smooth operation at up to 1800 rpm and approximately 3gpm (0.7 m3/hr).

Figure 7. APX Prototype and Test Stand 5 gpm (1.1 m3/hr)

Flows decrease rapidly at higher pressures indicating that the port plates and cylinder blocks are being affected by the interconnections and/or linkage. Additional testing and optimization of the design will continue into the next phase of this project.

3*.2 Future Plans*

As an option to the original ONR contract, OPT will build and test a 100 gpm (23 m3/hr) version of the APX in order demonstrate the suitability and efficiency of this technology for larger applications. The challenges associated with scaling up an APX include:

- Identifying and developing commercially available water hydraulic materials and technologies
- Hydrodynamic bearing development
- Cavitation control
- Pulsation and “water hammer” control

4.0 Conclusion

OPT has designed and prototyped a new kind of desalination pumping system that combines the benefits of water hydraulic axial piston pump technology with pressure exchanger energy recovery technology. This APX design promises to simplify the application and improve the system efficiencies of both small and larger desalination systems.

A major benefit to the APX design lies in its potential to save energy in full scale SWRO system trains on the order of 0.1-1 mgd (400-3,800 m3/day). Using current technology, these systems consume significantly more power than smaller systems because the main HP pump flows are too large for traditional positive displacement, high-efficiency plunger pumps to be practically applied. The result is that these systems consume approximately 20-25% more energy than their smaller counterparts. But, because of the water hydraulic rotary design of the APX, it is likely that this technology can be scaled up to provide a smooth flow, low maintenance and high efficiency solution. As part of a Phase II extension the original contract, OPT will develop and produce a scaled up prototype of the APX unit in order to demonstrate the suitability of this new technology for larger systems.

5.0 ACKNOWLEDGEMENTS

Below is a partial list of individuals and organizations who have participated and/or collaborated in this project.

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