MODULAR PUMPS BRING EFFICIENCIES

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Abstract

Positive displacement, water lubricated axial piston (AP) pump technology can be used in a modular arrangement to replace less efficient, centrifugal (CF) pumps that are currently the dominant solution for high pressure pumping used in large scale Seawater Reverse Osmosis (SWRO) Systems. A preliminary review of the modular positive displacement axial piston pump system reveals this new concept is not only a cost effective alternative to traditional centrifugal pump systems, but may have other advantages during the SWRO facility operating period.

I. Background

The axial piston (AP) pump/motor was invented in 1907 [1] and was the foundational product for the oil hydraulics power and motion industries of today [2].

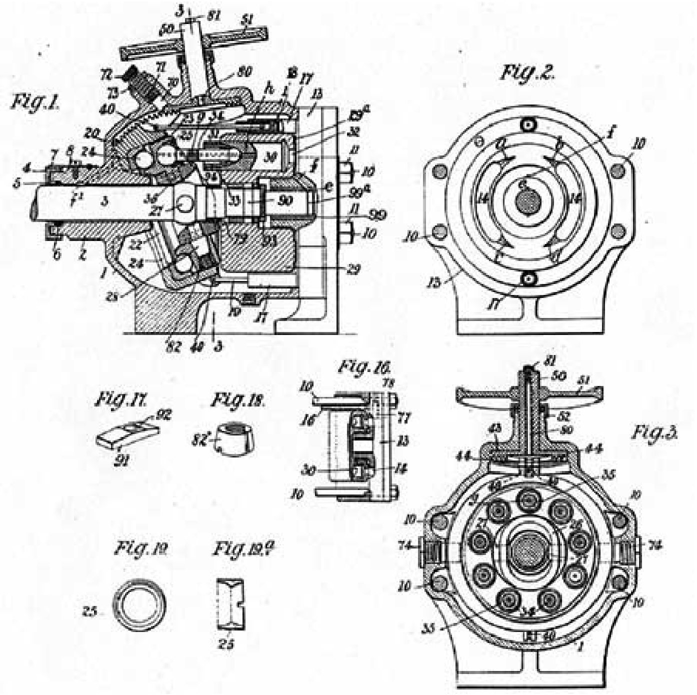


Figure 1 - Williams & Janney's Axial Piston Pump and Motor. ca. 1907 [2]

Although the axial piston pump has proven its utility in oil hydraulics for more than 100 years [3], it was not until the invention of modern composite and ceramic materials and precision manufacturing technologies that the unique axial piston design could be used with plain water. In the early 1980's through a public-private partnership with the British Government, a line of axial piston products that used plain water as the lubricating fluid instead of oil was developed. As a result, water lubricated axial piston pumps, motors and other products have been marketed and applied in water hydraulic systems since 1987 [4].

Water lubricated axial piston pump technology has been growing in popularity and by unit size in the SWRO industry for more than ten years. A "tipping point" exists for this technology to replace the less efficient centrifugal high pressure pumps that have dominated in large scale SWRO systems for more than 30 years. The axial piston pump can be efficiently and economically linked together in parallel to provide high pressure feed to any size system, including large municipal-scale plants.

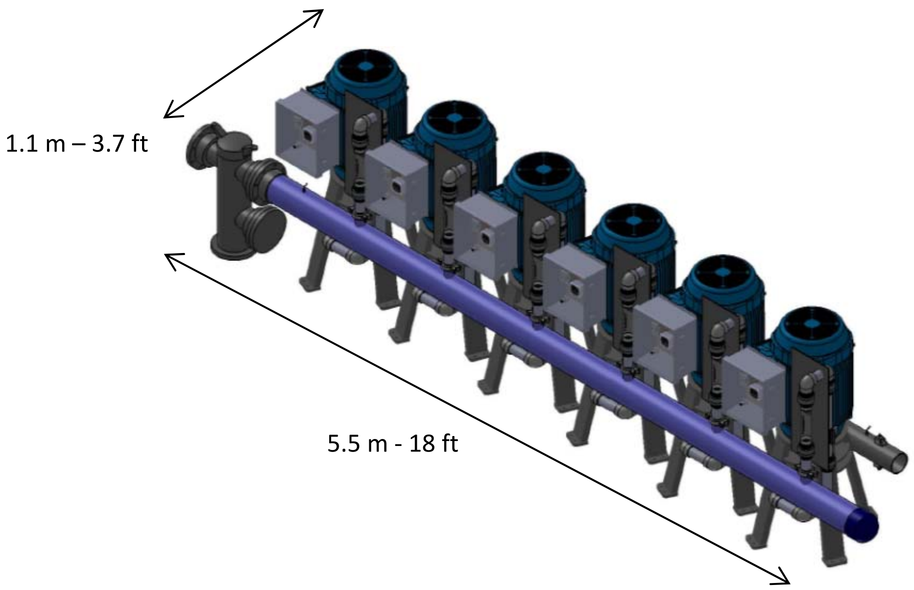
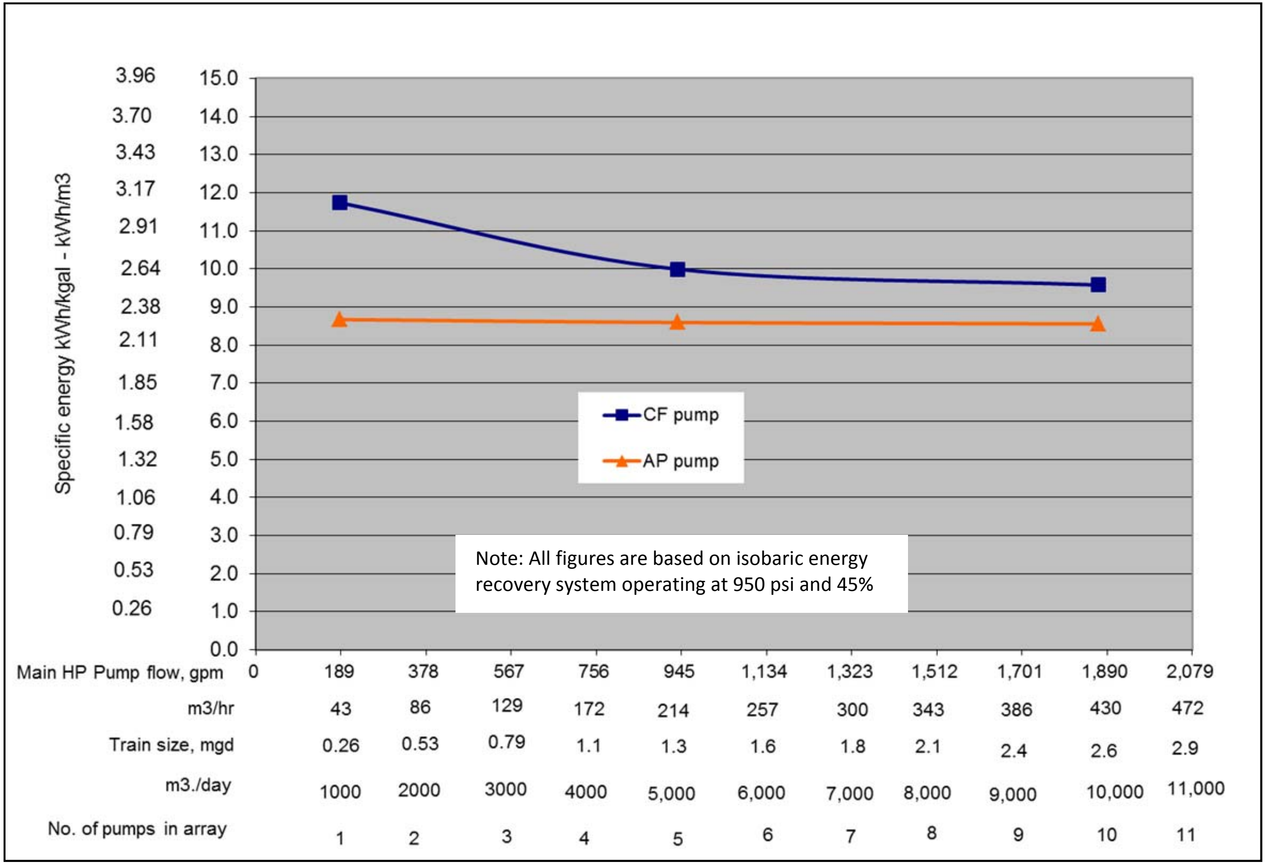


Figure 2 - Six Pump Array Provides up to 257 m3/hr (1,134 gpm) at 90% Efficiency

This kind of modular application in pumping systems was pioneered by Energy Recovery, Inc. and modular Pressure Exchanger (PX) arrays are now the standard for energy recovery in SWRO. Many parallels can be drawn between the modern axial piston pump and ERI's Pressure Exchanger because both operate on the same revolutionary technology platform of water lubricated bearings. When ceramic is used, these bearings can provide maintenance free operation for tens of thousands of hours. Furthermore, both devices employ a positive displacement axial piston design that results in very high efficiencies and virtually pulsation free flow. The progression in size of the axial piston pump has also been similar to the PX. The initial commercial PX units in 1995 produced only 9 m3/hr (40 gpm) and were therefore only considered suitable for smaller scale systems. But as the size of the individual PX units grew and their reliability in modular arrays was proven the technology became an industry standard applicable to the largest systems in the world. Similarly the modern water lubricated axial piston pump has grown in size from its original introduction into the SWRO market in 2000 with maximum capacities of approximately 10.2 m3/hr (45 gpm) to capacities up to 43 m3/hr (189 gpm) available today. Through its progression the water lubricated axial piston pump has also proven its compatibility in modular array applications.

The axial piston pump array requires up to 25% less power than the current SWRO industry's standard centrifugal (turbine) pump. Power is the single greatest operating cost in the seawater reverse osmosis process.

Figure 3. Specific Energy Consumption for AP and CF Pumps vs system Size



The efficiency advantage of the AP pump system shown in Figure 3 represents the largest single gain in desalination efficiency in 30 years. Looking at the X-axis one can see that as the train size increases axial piston pumps are added onto a pumping array. For example, a 4,000 m3/day (1.1 MGD) train would require four AP pumps running in parallel to produce 172 m3/hr (756 gpm) at a specific energy of 2.3 kWh/m3 (8.6 kWh/kgal) (approximately 90% pump efficiency) compared to the centrifugal pump’s 2.7 kWh/m3 (10.1 kWh/kgal) (approximately 76% pump efficiency). The 15% savings adds up to approximately US$58,000/year @ $ 0.10/kWh. In Figure 3 one can see how the CF pump energy consumption improves as the plant size increase. This is because CF pump efficiency improves as flow rate increases. This fact diminishes the AP efficiency advantage as the CF pump size increases.

II. Twenty Year Life Cycle Analysis

A comparative study was conducted to evaluate the AP modular pumping system at various flows to the life cycle cost of typical centrifugal pumps used in the SWRO industry. Three leading centrifugal pump manufacturers were considered including Energy Recovery Inc., KSB and Sulzer. The following flow rates and pump types were used in the study:

Table 1. Centrifugal Pump Flow Rates and Types

Pump Flow Rate	Pump Type
318 m3/hr - 1400 gpm	Centrifugal, “Canned”, 8 stages
568 m3/hr - 2500 gpm	Horizontal Ring Section, 3 stages
1136 m3/hr - 5000 gpm	Split Case, 3 stages

The study includes the evaluation of the high pressure pump system capital and operating expenses in order to determine the 20 year life cycle costs of each alternative. Preliminary capital cost evaluation not only includes the pump manufacturing, but also the following installation and support equipment associated with a high pressure pump system:

- Variable Frequency Drive (VFD) or Soft Start/RVS
- Electric Service Cable and Cable Installation
- Electrical Connectors
- Pump and Skid Install
- Motor, Drive, and Coupling Installation
- Pump Alignment
- Delivery Check Valve
- Relief Valve
- Delivery Pipework

2.1 System Performance Parameters

Certain SWRO operating parameters impact the overall performance of a given system. Table 2 provides a set of parameters as a basis for comparing the performance and subsequent operating costs for each pumping system at three different flow rates. Although we are focusing on the specific performance of the high pressure pumping system some parameters assume that the pumps are working in combination with an isobaric energy recovery system.

Table 2. System Performance Parameters and Assumption

Description	Units	318 m3/hr		568 m3/hr		1136 m3/hr		Axial Piston	
Pump type		8 Stage		Ring 3 Stage		Split 3 Stage		PD	
VFD efficiency	%	97.0%		97.0%		97.0%		n/a	
Motor efficiency	%	96.0%		96.0%		96.0%		95.0%	
Net pump efficiency	%	81.5%		83.0%		84.5%		90.0%	
Centrifugal (CF) slide wear rate (% eff loss/yr)	%/yr	0.3%		0.3%		0.3%		n/a	
Pump Flow rate	m3/hr - gpm	318	1,400	568	2,500	1,136	5,000	equal to CF	
Permeate flow rate (assumes isobaric)	m3/day - mgd	7,575	2.0	13,527	3.6	27,053	7.1	equal to CF	
Suction pressure	bar - psi	2.1	30	2.1	30	2.1	30	2.1	30
Discharge pressure	bar - psi	62.1	900	62.1	900	62.1	900	62.1	900
Power centrifugal (year 1)	kW	714		1,252		2,459		see AP power	
Power axial piston (AP)	kW	640		1,144		2,287		<---------	

Table 3. Cost Parameters and Assumptions

Cost Parameter Description	Unit	Value
Electric power (year 1)	$/kWh	0.15
Annual power cost increase	%	2%
Online factor	%	95%
Discount rate	%	5%
Plant operating period	years	20

2.2 CF Cost Parameters

The twenty year lifecycle costs were analyzed for the three flow rates specified in Table 1. Budgetary quotations were obtained from each manufacturer to determine the capital cost for each pump and motor package. In addition, quotations and estimates were obtained for the associated components required for installation including VFD’s, skids, piping and civil work.

Table 4. Centrifugal Pump Twenty Year Lifecycle Cost Parameters and Assumptions

Capitol Equipment Description			318 m3/hr	568 m3/hr	1136 m3/hr
Pump and motor			$ 195,000	$ 361,100	$ 426,400
VFD			$ 54,000	$ 100,000	$ 200,000
Service Cable			$ 1,000	$ 1,500	$ 2,500
Cable Install			$ 1,000	$ 5,000	$ 5,000
Connectors			$ 250	$ 750	$ 750
Pump and Skid Install			$ 10,000	$ 15,000	$ 15,000
Motor Install			$ -	$ 5,000	$ 5,000
Drive Install			$ 5,000	$ 10,000	$ 10,000
Coupling Install			$ 1,000	$ 5,000	$ 5,000
Allignment			$ 5,000	$ 5,000	$ 5,000
Delivery Check Valve			$ 15,000	$ 25,000	$ 35,000
Delivery Pipework			$ -	$ 35,000	$ 45,000
Extra Civils, Pad, Steel			$ 10,000	$ 15,000	$ 25,000
Total 20 year CF Installation and CAPEX			$ 297,000	$ 583,000	$ 780,000
Spare Part/Consumable Desciption	Qty		318 m3/hr	568 m3/hr	1136 m3/hr
Mechanical Seals	2		$ 2,000	$ 2,500	$ 5,000
Oil	lot		$ 500	$ 750	$ 1,000
Coupling	1		$ 500	$ 2,000	$ 3,000
10 year rebuild @ 50% Pump Capex	1		$ 75,000	$ 141,610	$ 140,314
15 year rebuild @ 50% Pump Capex	1		$ 75,000	$ 141,610	$ 140,314
Total CF 20 year spares/consumable costs			$ 153,000	$ 288,000	$ 290,000
Labor Description	Hours	Rate $/hr	318 m3/hr	568 m3/hr	1136 m3/hr
General operation and maintenance (hrs/wk)	1	$ 25	$ 26,000	$ 26,000	$ 26,000
Rebuild 10 year	40	$ 150	$ 6,000	$ 9,000	$ 12,000
Rebuild 15 year	40	$ 150	$ 6,000	$ 9,000	$ 12,000
Total CF 20 year O&M labor			$ 38,000	$ 44,000	$ 50,000
Energy costs			318 m3/hr	568 m3/hr	1136 m3/hr
Lifecycle energy costs			$ 22,070,000	$ 38,698,000	$ 76,022,000

All currencies are in US$. It's assumed that the 10 year CF rebuild recovers some of the slide wear efficiency loss back to 3 years new and that the 15 year rebuild provides no benefit to efficiency.

2.3 AP Cost Parameters

The twenty year lifecycle costs for the AP system were also analyzed at the three flow rates specified in Table 1. Pump and spare parts budget estimates were obtained using axial piston pump manufacturer's list pricing. In addition, quotations and engineering estimates were obtained for the associated components required for installation including switch gear, skids, piping and civil work.

Table 5. Axial Piston Pump Twenty Year Lifecycle Cost Parameters and Assumptions

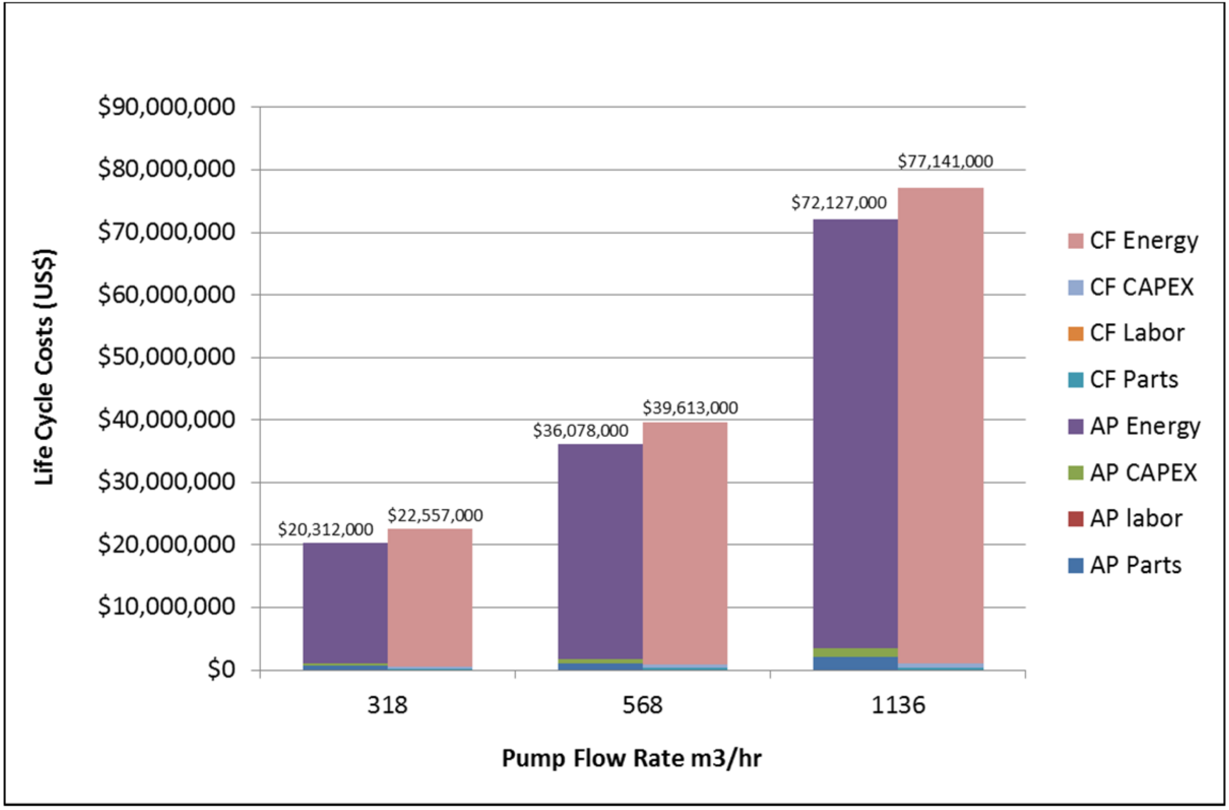
		m3/hr	318	568	1136
Capitol Equipment Description		Unit cost	# Units: 8	# Units: 13	# Units: 26
Axial piston pump (196 gpm max flow)		$ 34,780	$ 278,240	$ 452,140	$ 904,280
Motor		$ 7,000	$ 56,000	$ 91,000	$ 182,000
DOL starters		$ 4,500	$ 36,000	$ 58,500	$ 117,000
MCC Surcharge		$ 1,500	$ 12,000	$ 19,500	$ 39,000
Check Valves		$ 1,500	$ 12,000	$ 19,500	$ 39,000
Relief valve (rupture disc)		$ 600	$ 4,800	$ 7,800	$ 15,600
Victaulic high pressure		$ 75	$ 600	$ 975	$ 1,950
Victaulic low pressure		$ 50	$ 400	$ 650	$ 1,300
LP Flow Meters		$ 150	$ 1,200	$ 1,950	$ 3,900
Base mount		$ 500	$ 4,000	$ 6,500	$ 13,000
Manifolds		$ 1,500	$ 12,000	$ 19,500	$ 39,000
Total 20 year AP Installation and CAPEX		$ 52,000	$ 417,000	$ 678,000	$ 1,356,000
Spare parts/consumables description	Unit cost	/pmp/yr	# Units: 8	# Units: 13	# Units: 26
Piston set	$ 3,700	33%	$ 195,360	$ 317,460	$ 634,920
Valve and port plate set	$ 2,400	20%	$ 76,800	$ 124,800	$ 249,600
Cylinder block	$ 8,000	20%	$ 256,000	$ 416,000	$ 832,000
Swash plate	$ 2,500	20%	$ 80,000	$ 130,000	$ 260,000
Shaft seal	$ 900	20%	$ 28,800	$ 46,800	$ 93,600
Special tools	$ 1,300	n/a	$ 2,600	$ 2,600	$ 2,600
Total 20 year AP spares/consumable costs			$ 640,000	$ 1,038,000	$ 2,073,000
Labor Description	Hours	Rate $/hr	# Units: 8	# Units: 13	# Units: 26
General maintenance hrs/wk	1	$ 25	$ 26,000	$ 26,000	$ 26,000
Annual rebuild (hours/pmp)	2	$ 25	$ 8,000	$ 13,000	$ 26,000
Total AP 20 year O&M labor			$ 34,000	$ 39,000	$ 52,000
Energy costs			# Units: 8	# Units: 13	# Units: 26
Total life cycle energy			$ 19,221,000	$ 34,323,000	$ 68,646,000
Savings			# Units: 8	# Units: 13	# Units: 26
Average annual energy savings			$ 142,000	$ 219,000	$ 369,000
Average annual life cycle savings			$ 112,000	$ 177,000	$ 251,000

*All currency in US$.

2.4 Twenty Year Life Cycle Costs

Looking at Figure four below, CF energy costs on average consume 98% of their total twenty year life cycle costs. Energy consumed by the high pressure pump typically consumes as much as 50% of the total operating cost to produce water within the overall SWRO process [5]. Therefore, high pressure pumping efficiency is of utmost importance when targeting ways to improve the overall efficiency and operating costs for SWRO.

Figure 4. Total Twenty Year Life Cycle Costs



III. Present Worth and Return on Investment (ROI)

Both the Present Worth Costs and Payback Period show that the AP system holds a strong advantage over traditional centrifugal pumps. Even in the extreme case at 1136 m3/hr payback is less than three years. Payback is less than one year for the 318 and 568 systems.

Table 6. Present Worth Costs and ROI

Present Worth and ROI m3/hr	318	568	1136
AP present worth costs	$13,151,000	$23,339,000	$46,660,000
CF present worth costs	$14,140,000	$24,849,000	$48,296,000
Pay back period (Capex differential/avg annual life cycle savings)	1.1	0.5	2.3
Return on investment (ROI)	93%	186%	44%

IV. Weight and Dimensions

Looking at the overall installed weight and dimensions shows that CF systems still possess an advantage over the AP system. However, just looking at the pump weight, the AP pumps are significantly lighter below 568 m3/hr. Less weight should correlate to lower materials and consequent manufacturing costs as the volume of AP pumps being applied in the market place increases.

Table 7. Weight and Dimensional Comparison

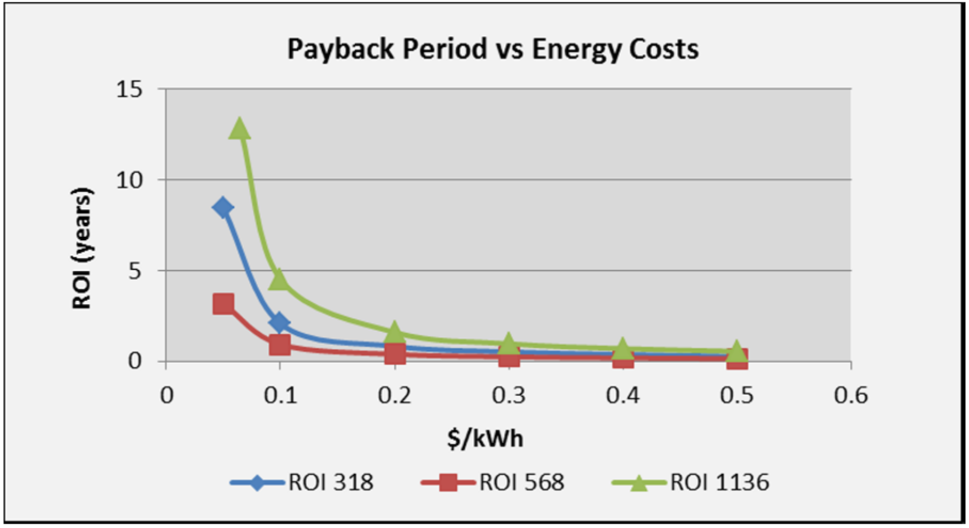
Description	Units		318		568		1136	
Pump weight	kg - lbs		1,279	2,820	1,500	3,307	1,991	4,389
Motor weight	kg - lbs		3,175	7,000	7,600	16,755	5,750	12,676
Base plate	kg - lbs		800	1,764	3,000	6,614	1,200	2,646
Grout base plate	kg - lbs		n/a	n/a	2,825	6,228	4,708	10,379
Installed weight	kg - lbs		5,254	11,583	14,925	32,904	13,649	30,091
Package dimension	L x W x H, m - ft		5.0x1.2x1.0	16.4x3.9x3.3	4.8x2.0x2.8	15.7x6.6x9.1	4.8x2.0x2.6	15.7x6.6x8.5
Area	m^2 - ft^2		6.0	64	10	104	8.2	104
AP Weight and Dims	Per AP Module		# Units:	**8**	# Units:	**13**	# Units:	**26**
Pump weight (kg - lbs)	91	201	728	1,605	1,183	2,608	2,366	5,216
Motor weight (kg - lbs)	757	1,669	6,056	13,351	9,841	21,695	19,682	43,391
Installed weight (kg - lbs)	948	2,090	7,584	16,720	12,324	27,169	24,648	54,339
Package dimension (L x W x H, m - ft)	0.9x1.1x1.8	3.0x3.7x6.0	7.2x1.1x1.8	24.0x3.7x6.0	11.7x1.1x1.8	39x3.7x6	23 x 1.1 x 1.8	78 x 3.7 x 6
Area (m^2 - ft^2)	1	11	8	88	13	143	26	286

Possibilities exist for improving the AP systems overall weight and dimensions including increasing the individual pump unit size and/or increasing the number of pumps per motor through a double motor shaft configuration.

V. Sensitivity Analyses

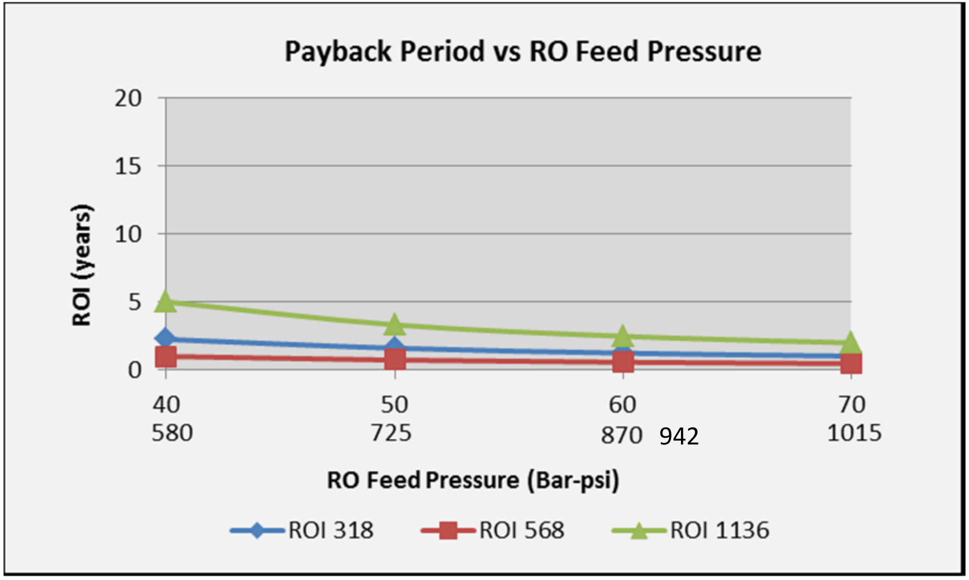
Using the standard set of costs and conditions established in Tables 1-5, the figures below show how varying energy costs, RO feed pressure, CF capital costs and AP spare parts costs impacts the return on investment for the AP system.

Figure 5. Payback Period Versus Energy Costs



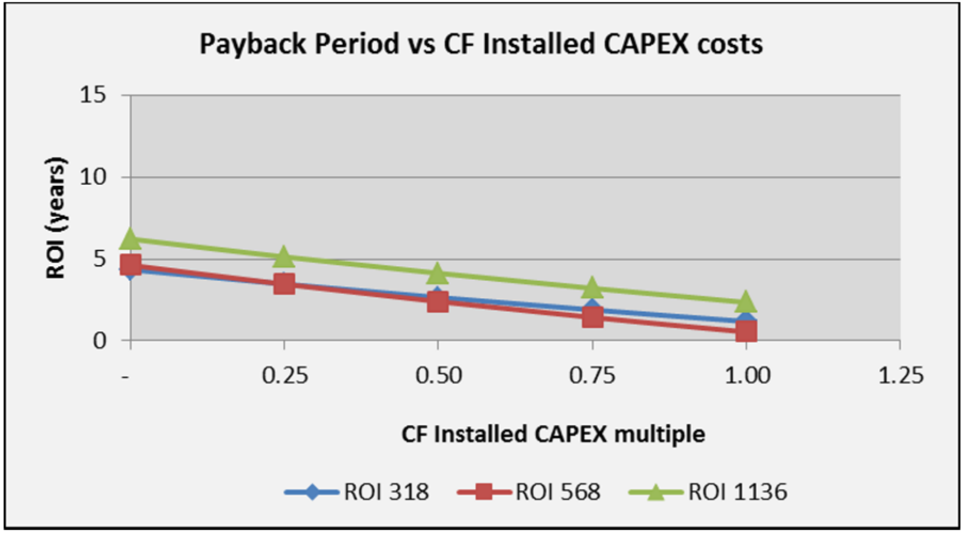
Energy costs obviously play a significant role and give the AP system a decisive advantage where power costs are high. Even at $0.10/kWh the AP system yields a less than five year return on investment over the entire flow range considered. However as the pump flow rate increases to 1136 m3/hr, the AP system's diminished efficiency advantage and added spare parts burden pushes the ROI to beyond 12 years at $0.065/kWh.

Figure 6. Payback Period Versus RO Feed Pressure



Another important factor that impacts energy consumption and thus the payback period for an energy saving high pressure pump is the RO feed pressure. RO feed pressures typically range between 45-69 bar (650-1000 psi) depending on membrane technology, age, condition and other operating conditions. With the introduction of Nano based membranes and competition between membrane manufacturers, RO feed pressure between 45-55 bar (650-800 psi) are common today. Figure 6 shows that at the lowest feed pressures the AP system still provides a quick return when compared to CF pumps. Even the 1,136 m3/hr AP system yields a 20% return on investment (5 year payback) over the CF system at a feed pressure of 40 bar (580 psi).

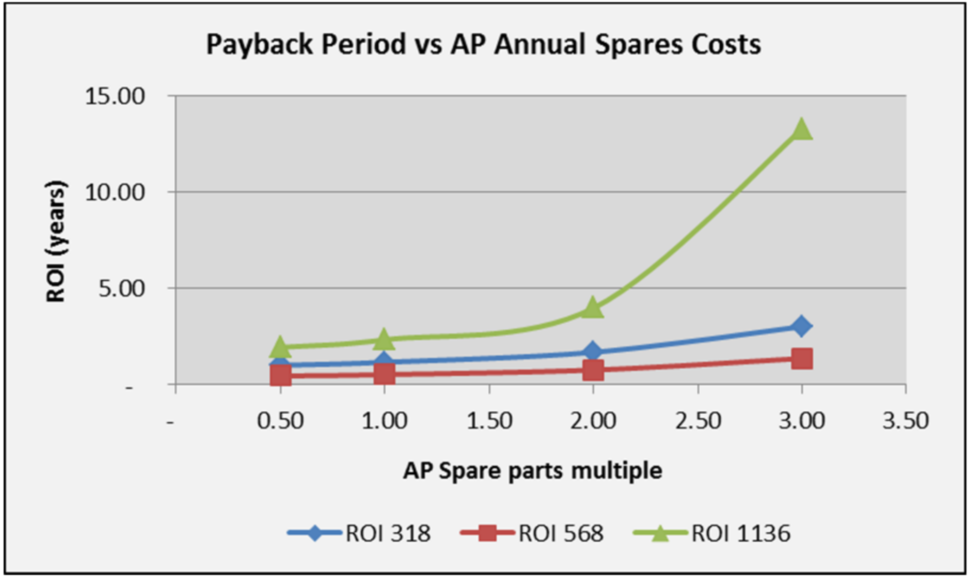
Figure 7. Payback Period Versus CF Installed CAPEX Costs



The installed AP system costs were 45% more expensive than the CF system on average over the three scenarios. The estimated installed CAPEX costs were based on engineering estimates and actual quotations from the pump manufacturers and other major component suppliers. Manufacturers' quotations are subject to significant variations from initial budgetary pricing to final/best firm fixed price quotations in addition to volatility in commodity materials pricing. Therefore, we also considered the sensitivity of payback versus the Total 20 year CF Installation and CAPEX costs. In Figure 7 a multiplier of 0-1 was applied to the Total 20 year CF Installation and CAPEX costs and plotted against the payback period on the vertical axis. A multiplier of zero correlates to zero CF Installation and CAPEX costs and a multiplier of one corresponds to the same CAPEX costs given in Tables 4.

It should be noted that over the range of flows considered in this study, on average 25% of the lifecycle energy savings are offset by AP system spare parts replacement expenses. The primary reasons for replacement include wearing of the sliding/bearing surfaces which decrease the overall efficiency and reliability of axial piston pumps. Water quality can play a major role in the life expectancy of water lubricated machinery because small particulates in the RO feed water (lubricating fluid) can accelerate the wear on the bearings. This is particularly true in the case of the plastic-stainless bearings used by some manufacturers. On the other hand, one AP pump manufacture uses ceramic-ceramic bearings and claims extended service intervals over the plastic-stainless steel bearings. Therefore a sensitivity analysis was performed varying the replacement cost/interval for a typical AP system. Similar to the capital cost analysis a multiplier of 0.5-3 was used to adjust the Total AP 20 Year AP Spares/Consumables Costs shown in Table 5.

Figure 8. Payback Period Versus AP Annual Spares Costs



Applying a multiplier of 0.5 reduces Total 20 Year Spares/Consumables Costs by a factor of 2 or equivalently extends the assumed replacement intervals by 2X, while a multiplier of three increases the Total 20 Year Spares/Consumables Costs by a factor of three or equivalently shortens the assumed replacement intervals by one third. A multiplier of one corresponds to the same spares and consumables costs and replacement interval (/pump/year) found in table 5.

VI. Conclusions

In addition to the obvious energy efficiency advantage that positive displacement pumps maintain over centrifugal units, the technology also improves the operation and control of the system there by yielding additional gains in the net system efficiency. There are also potentially significant cost efficiency gains related to manufacturing and building modular systems around a standardized unit.

Some of the advantages and disadvantages associated with the Modular High Pressure Pump System using Axial Piston Pump Technology include the following:

Advantages

- Significant energy savings due to the 90% efficiency of positive displacement pumps compared to centrifugal pump designs.
- Applying one standardized high efficiency pump as a building block in multi-unit modules allows smaller trains to be as efficient as the largest systems.
- A standardized modular design reduces inventory requirements for spare parts. Relatively small and inexpensive service kits and spare parts can support modular arrays whereas large centrifugal pumps require massive spare motor(s) and/or rotor kits, mechanical seals, etc.
- Lead times for large centrifugal pumps are significant and substantially lengthen project deliveries whereas axial piston pumps can be kept on the shelf and used as building blocks for any size system to significantly reduce project delivery times.
- Smaller standardized pumps can be maintained in-house with minimum staff training compared to large centrifugal pumps, which require specialized factory trained technicians and/or shipping equipment back to factory for maintenance and repairs. This will significantly decrease down-time in facilities using Axial Piston Pump technology.
- No huge VFD or RVS are required. Axial Piston Pumps can be started across the line (depending on country and electrical supply requirements) due to the smaller individual motors.
- No regulating valve or VFD is required to control AP pumps, which further improves the overall system efficiency compared to centrifugal pump process designs.
- Low voltage power can be used to drive smaller motors arranged in a modular array.
- Virtually eliminates in rush current associated with starting large electric motors.
- Smaller individual pumps arranged in a modular array allow for additional system flow control by turning pumps on or off within the array while maintaining peak efficiency and optimal power usage.
- Multiple-small diameter discharge check valves are less expensive and have less lead time than large, exotic alloy valves due to the specialized nature of the large valve industry.
- No complex shaft alignment required with close coupled axial piston pumps

Disadvantages

- More plant space may be required for the axial piston pump modular array, though less electrical space will be required.

- Longer installation and commissioning period may be required due to multiple pumps and components
- Multi-start system opposed to one larger centrifugal pump may lead to a longer start-up time.
- More instrumentation (flow meters on each pump on the array) may be required, but will provide additional data for troubleshooting and system efficiency monitoring.
- The efficiency of centrifugal pumps increases with flow rate reducing the efficiency advantage of the modular axial piston pump concept at the higher end.
- Additional spare parts, maintenance and down time are needed although the service intervals are predictable.

VII. REFERENCES

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